Chemistry
S 40.5
I58
P49

VOL. 3. JUNE, 1917. NO. 12.

JOURNAL

OF

THE INSTITUTION

OF

PETROLEUM

TECHNOLOGISTS

AND

RECORD OF TRANSACTIONS.

FOUNDED 1913—INCORPORATED 1914.

PUBLISHED BY
THE INSTITUTION OF PETROLEUM TECHNOLOGISTS,
17, GRACECHURCH STREET, E.C.,
AND PRINTED BY
CROWTHER & GOODMAN, LIMITED,
124, FENCHURCH STREET, LONDON, E.C.

PRICE 5s.

All rights of Publication or Translation are reserved.

MODERN REFINERY WORK.

COMPLETE PLANTS - AND MACHINERY -

SUPPLIED FOR

Acid Pumping by New Method.
Asphalt Distilling.
Benzine, Kerosine and Lubricating Oil Washing.
Benzol Recovery.
Continuous Benzine Rectification.
Continuous Crude Oil Distillation.
Continuous Residue Distillation.
Continuous Vacuum Oil Distillation for Lubricating & Vacuum Oils.
Continuous Petrol Washing.
Cracking and Coking Distilling.
Debenzination of Crude Oil.
Lignite Distillation.
Paraffin Extraction and Refining.
Petrol Rectifying.
Pumping Installations.
Shale Distillation.
Sulphuric Acid Recovery.
Uncondensable Gas Plant and Benzine Enrichment.
Vacuum Continuous Lubricating Oil Distillation.

Stills, Retorts, Superheaters, and Montejus for all Purposes.

NEW PLANTS DESIGNED TO SUIT SPECIAL REQUIREMENTS.

WRITE FOR PAMPHLET ON MINERAL OIL DISTILLATION.

W. J. FRASER & CO., LTD.,

ENGINEERING WORKS,

DAGENHAM, ROMFORD, ESSEX.

Telegrams:
"FRASER, DAGENHAM."

Telephone:
222 ROMFORD (2 lines).

LIST OF THE OFFICERS

OF

The Institution of Petroleum Technologists, 1917—1918.

Past Presidents:

Sir BOVERTON REDWOOD, Bart., D.Sc., F.R.S.E. (1914-1916).
Professor JOHN CADMAN, C.M.G., D.Sc., M.Inst.C.E. (1916-1917).

President:

CHARLES GREENWAY.

Vice-Presidents:

Professor JOHN CADMAN, C.M.G., D.Sc., M.Inst.C.E.
The Rt. Hon. VISCOUNT COWDRAY OF COWDRAY.
Sir THOMAS H. HOLLAND, K.C.I.E., D.Sc., F.R.S.
Sir BOVERTON REDWOOD, Bart., D.Sc., F.R.S.E.

Members of Council:

ALFRED C. ADAMS.
HERBERT ALLEN.
Sir ROBERT BALFOUR, Bart., M.P.
Capt. R. W. BARNETT, M.P.
HERBERT BARRINGER, M.Inst.C.E., M.I.Mech.E., M.I.N.A.
Sir GEORGE BEILBY, LL.D., F.R.S.
EDWIN R. BLUNDSTONE, B.A., F.C.S.
ANDREW CAMPBELL.
JOHN T. CARGILL.
E. H. CUNNINGHAM CRAIG, B.A., F.R.S.E., F.G.S.
ARTHUR W. EASTLAKE, M.Inst.M.E., A.M.I.Mech.E.
T. C. PALMER, Assoc.M.Inst.C.E.
F. MOLLWO PERKIN, Ph.D., F.I.C., F.C.S.
ROBERT REDWOOD, F.C.S.

Honorary Treasurer:

Sir WILLIAM PLENDER.

Honorary Solicitor:

Sir FRANK CRISP, Bart.

Honorary Auditors:

Messrs. PRICE, WATERHOUSE & Co.

Bankers:

THE LONDON COUNTY AND WESTMINSTER BANK, LIMITED.
21, Lombard Street, London, E.C. 3.

Hon. Editor and Librarian:

W. H. DALTON, F.G.S., F.C.S.

Hon. Secretary:

ARTHUR W. EASTLAKE, M.Inst.M.E., A.M.I.Mech.E.
Offices, 17, Gracechurch Street, London, E.C. 3.

COMMITTEES.

ELECTION, FINANCE AND PUBLICATION.

Members of the Election Committee.

Sir GEORGE BEILBY, LL.D., F.R.S.
EDWIN R. BLUNDSTONE, B.A., F.C.S.
Professor JOHN CADMAN, C.M.G., D.Sc., M.Inst.C.E.
ARTHUR W. EASTLAKE, M.Inst.M.E., A.M.I.Mech.E.
Sir THOMAS H. HOLLAND, K.C.I.E., D.Sc., F.R.S.
T. C. PALMER, Assoc.M.Inst.C.E.
Sir BOVERTON REDWOOD, Bart., D.Sc., F.R.S.E.
CHARLES GREENWAY (*ex officio*).

Members of the Finance Committee.

ALFRED C. ADAMS (*Chairman*).
ARTHUR W. EASTLAKE, M.Inst.M.E., A.M.I.Mech.E.
T. C. PALMER, Assoc.M.Inst.C.E.
ROBERT REDWOOD, F.C.S.
CHARLES GREENWAY (*ex officio*).

Members of the Publication Committee.

Sir GEORGE BEILBY, LL.D., F.R.S.
EDWIN R. BLUNDSTONE, B.A., F.C.S.
Professor JOHN CADMAN, C.M.G., D.Sc., M.Inst.C.E.
Sir THOMAS H. HOLLAND, K.C.I.E., D.Sc., F.R.S.
F. MOLLWO PERKIN, Ph.D., F.I.C., F.C.S.
Sir BOVERTON REDWOOD, Bart., D.Sc., F.R.S.E.
CHARLES GREENWAY (*ex officio*).

Two Sub-Committees have been appointed to investigate respectively the

DESULPHURISATION OF SHALE OILS,

and

OIL-SHALE RESOURCES.

CONTENTS.

PAGE

Council and Officers i

Committees ii

General Notices:—

Copyright iv

Issue of Journal iv

Changes of Address iv

To Authors of Papers iv

The Library v

Advertisements in the Journal vii

List of Advertisers vii

Personal Notes of Members, and Special Notices viii

Editorial:—Mineral Rights 255

Twenty-second General Meeting, 17th April, 1917:—

Presidential Address, by Charles Greenway 257

Vote of Thanks, by Prof. Cadman and Sir Boverton Redwood... 261

Paper: The Development of the Petroleum Industry in Assam, by H. S. Maclean Jack 263

Discussion: by the President, Sir Boverton Redwood, Mr. W. H. Dalton, Mr. E. H. Cunningham Craig, Dr. F. M. Perkin, Mr. A. MacDougall, Prof. Cadman, and Mr. W. J. A. Butterfield 276

Later notes by Messrs. M. A. Ockenden, A. Carter, and H. May 283

Twenty-third General Meeting, 15th May, 1917:—

Paper: The Estimation of Toluene in Crude Petroleum, by S. E. Bowrey, B.Sc. (Lond.) 287

Discussion: by Mr. A. Duckham, the President, Prof. J. S. S. Brame, Dr. F. M. Perkin, Mr. H. V. Mitchell, Dr. A. E. Dunstan, and Dr. F. B. Thole 305

NOTICES.

The Institution as a body is not responsible for the statements or opinions expressed in any of its publications.

Copyright. The entire contents of the Journal are covered by general copyright, and official permission is necessary for reprinting long abstracts; but editors may use not more than three pages of any paper, provided that credit is given as reproduced from the Journal of The Institution of Petroleum Technologists or advance-proofs thereof.

Issue of Journal. The Journal appears in four parts per sessional volume, viz. in December, February, April and June. A brochure describing the origin, progress and purposes of the Institution, and comprising also the Memorandum and Articles of Association, the By-Laws and Regulations of the Institution, the Library Catalogue to date (with subject index), and the List of Members, was published in September, 1915, to be followed annually by revisions of the Library Catalogue and List of Members.

Members of all classes are entitled to receive these publications free: for additional copies of the Journal they will be charged at the price of five shillings per part, and of the brochures at the prices stated on the wrappers, varying in proportion to bulk.

Changes of Address. It is particularly requested that members notify the Secretary immediately of any change of address; and members are also requested to advise the Parcel-Post Department as well as the Letter Office, of any temporary change of address, as, unless this is done, parcel-post packets will not be re-addressed; but will be returned to the offices of the Institution in London, thus incurring further expense for postage.

To Authors of Papers. Papers should be written in the third person, and the copy should be carefully corrected by the author before it is presented.

All drawings, diagrams or other illustrations should be sent in a fit state for direct photographic reproduction.

All quotations, technical terms, and localisms should be indicated by means of inverted commas.

Foreign weights, measures, and costs should be given whenever possible; and also their English equivalents.

It is suggested that authors append as complete a bibliography of the subject treated as may be possible.

All papers and notes submitted to the Institution are supposed to be original communications unless distinctly stated to be otherwise, in which case the exact reference to the previous publication should be given.

Communications upon papers read at meetings, notices of personal movements, or other matter for which publication is desired in the next issue of the Journal, should be in the hands of the Editor on or before the last day of January, March, May or November as the case may be. Subsequent delivery may be too late for insertion.

The Library. In the full catalogue of the Library, published in our brochure of September, were included the titles of such papers in journals received as bear upon any subject within the purview of the Institution. Such titles are not included in the intermediate lists given in our several parts, where, as below, the journals received are acknowledged in single entries.

The attention of such of our members as are authors is directed to the absence of their works from the Library, (with some exceptions), and we shall be particularly thankful for gifts of treatises on special branches of technology, and for separate copies of papers contributed to other Institutions and to journals, either in past or future.

Additions to Library.

American Chemical Society. The Journal of Industrial and Engineering Chemistry, vol. ix, pts. 5, 6. 1917.* *By Exchange.*

Anglo-Mexican Petroleum Co., Ltd. (and affiliated Cos.), A Record of the Members of the Staffs and Employees serving with H.M. Forces. 4to, *London*, 1916. *From the Secretary.*

Barnett, V. H. Geology of the Hound Creek District of the Great Falls Coalfield, Cascade County, Montana. *Bull. U.S. Geol. Surv.*, no. 641, pp. 215–231, pl. xxii. 1916.

Calvert, W. R. Geology of the Upper Stillwater Basin, Stillwater and Carbon Counties, Montana, with special reference to Coal and Oil. *Bull. U.S. Geol. Surv.*, no. 641, pp. 199–214, pls. xx, xxi. 1916.

Canada Department of Mines. Geological Survey Memoirs, nos. 88, 94. 1916, 1917. *By Exchange.*

* An addition to our Exchange List, not here reprinted.

Cassier's Engineering Monthly, vol. li, nos. 5, 6. 1917.
From Arthur W. Eastlake.

Diesel Engine Users Association. Particulars of the Association, List of Members, etc. 8vo, *London*, 1917.

Drysdale, C. W. Ymir Mining Camp, British Columbia. *Canada Geol. Survey Memoir* no. 94, 1917.

Gas and Oil Power, vol. xii, nos. 140, 141. 1917.

Hares, C. J. Anticlines in Central Wyoming. *Bull. U.S. Geol. Surv.* no. 641, pp. 233–279, pl. xxiii. 1916.

Hopkins, O. B. Structure of the Vicksburg-Jackson Area, Mississippi, with special reference to Oil and Gas. *Bull. U.S. Geol. Surv.*, no. 641, pp. 93–120, pl. viii. 1916.

Institution of Mining and Metallurgy, Bulletin, nos. 152, 153. 1916, 1917.

Institution of Mining Engineers, Transactions, vol. lii, pt. v: vol. liii, pt. ii. 1917.

Junior Institution of Engineers, Journal and Record of Transactions, vol. xxvii, no. 6. 1917.

Kahncrete Engineering, vol. iv, no. 19. 1917.

MacKenzie, J. D. Geology of Graham Island, British Columbia. *Canada Geol. Survey Memoir* no. 88. Pp. viii, 221; 16 pls., 2 maps. 1916.
Petroleum &c., pp. 158–171.

Marine Engineer and Naval Architect, vol. xxxix, pts. 10, 11. 1917.

Matson, G. C. The Caddo Oil and Gas Field, Louisiana and Texas. *Bull. U.S. Geol. Surv.*, no. 619. Pp. 62, 8 pls. 1916.

Northrop, J. D. Petroleum in 1915. *Min. Res. U.S.*, 1915, pt. ii, pp. 559–760. 1916.

Oil Age, vol. xiii, nos. 4, 5. 1917.

Oil and Colour Trades Journal, vol. l, nos. 968–976. 1917.

Oil Exchange Weekly Price List. May 3–June 28, 1917.
By Exchange.

Oil News. May 5–June 30, 1917.

Petroleum World, vol. xiv, nos. 5, 6. 1917.
From Sir Boverton Redwood.

Porter, G. Tar Oil Fuel and Diesel Engines. *Diesel Engine Users Assoc.*, May 24, 1917.

Robinson, H. M. Ozokerite in Central Utah. *Bull. U.S. Geol. Surv.*, no. 641, pp. 1–16, pl. i. 1916.

Royal Society of Arts, Journal, vol. lxv, nos. 3363–3371. 1917. *By Exchange.*

Shipbuilder, Annual Number, 1917. *From the Editor.*

Skinner, W. R. The Oil and Petroleum Manual, 1917. 8vo, *London*, 1917. *Purchased.*

Society of Chemical Industry, Journal, vol. xxxvi, nos. 8–11. 1917.

Stebinger, E. Possibilities of Oil and Gas in North-Central Montana. *Bull. U.S. Geol. Surv.*, no. 641, pp. 49–91, pls. iv–vii. 1916.

United States Geological Survey, Bulletins, nos. 602, 619, 641 A, C, D, F–I. 1916.

United States Patent Office, Official Gazette, vol. 238, 239, pt. i. 1917.

Wegemann, C. H. Anticlinal Structure in Parts of Cotton and Jefferson Counties, Oklahoma. *Bull. U.S. Geol. Surv.*, no. 602. Pp. 108, pl. and map. 1915.

Winchester, D. E. Oil Shale in Northwestern Colorado and adjacent Areas. *Bull. U.S. Geol. Surv.*, no. 641, pp. 189–198, pls. x–xix. 1916. *By Exchange.*

Zanetti, J. E. The Thermal Decomposition of the Propane-Butane fraction from Natural-Gas Condensate. *Journ. Ind. Eng. Chem.*, vol. viii, pp. 674–678. 1916. (Exc.)

Zanetti, J. E., and G. Egloff. The Thermal Decomposition of Benzene. *Ibid.*, vol. ix, pp. 350–356. 1917. (Exc.)

Zanetti, J. E., and E. H. Leslie. The Thermal Decomposition of the Ethane-Propane fraction from Natural-Gas Condensate. *Ibid.*, vol. viii, pp. 777–779. 1916. (Exc.)

From Mr. Zanetti.

Advertisements in the Journal. A limited number of Advertisements of firms interested in the Petroleum Industry, may be inserted in the Journal. Application for terms etc., should be made to the Secretary.

Members are desired, when making enquiries or placing orders with advertisers, to mention that they have seen their announcement in the Journal.

LIST OF ADVERTISERS.

Blair, Campbell & McLean, Ltd.
W. Christie & Grey, Ltd.
W. J. Fraser & Co., Ltd.
Hayward-Tyler & Co., Ltd.
Oil Well Supply Co.
University of Birmingham.
W. H. Willcox & Co., Ltd.

PERSONAL NOTES OF MEMBERS AND SPECIAL NOTICES.

It is suggested that Members of the Institution send information regarding their movements to the Secretary for insertion under this heading.

Mr. F. D. Brown is now serving as a gunner in the Canadian Field Artillery.

Prof. John Cadman, C.M.G., has been appointed by the Council to represent the Institution on the Board of Scientific Societies.

Mr. William Calder returned to England in May from Russia.

Mr. Stanley H. Chapman has returned from Sumatra, after being there from 1911 to 1916. On his return he visited the oilfields of California, and is at present engaged in the Petroleum Research Department of the Ministry of Munitions.

Mr. H. W. Hole has returned to England from Persia.

Mr. Laurence Owen is a 2nd Lieutenant in the 183rd Tunnelling Co., Royal Engineers, and is now on Active Service on the Western Front in France.

Sir Boverton Redwood has been elected a Vice-President of the Royal Society of Arts.

Mr. J. J. Whitehead, D.S.O., is now a Lieutenant-Colonel in the 17th Battalion Manchester Regiment, British Expeditionary Force.

Address wanted :—L. J Bates.

UNIVERSITY OF BIRMINGHAM.

PETROLEUM ENGINEERING COURSE.

The Course of study extends over three years, and leads to the Degree of B.Sc.

The Session commences in October.

Full particulars of the Course can be obtained from the Secretary of the University.

EDITORIAL.

Mineral Rights.

It must have been shortly after that comparatively early stage in the development of civilisation when the right of private possession began to extend from that vested in portable property only, to the less ponderable consideration of the occupation of land, that the utilisation of mineral matter opened a Pandora's box of troubles in the form of questions of access, water-supply, drainage, lateral support and the like more or less superficial sources of dispute, to be followed later, as operations were carried deeper, by litigation as to identity or otherwise of veins, damage at surface attributed to excavation, &c., &c.

The subsidences due to coal-mining and brine-pumping were easily assignable to their respective causes, but where, in recent years, asphalt beds on the surface were under other ownership than the oil-stores which fed them from beneath, there arose greater complexity, from the obscurity necessarily involving the course of the subterranean passages, whose existence could only be inferred, and not demonstrated as fact.

Of late years the view has been advanced, with at least considerable plausibility, that mineral wealth, not being the product of industry, should all vest in the State, for the benefit of the entire body politic. That this view is not wholly modern is evident from the reservation of certain valuable minerals in Royal land-grants of some centuries past. It has been urged on the other hand, that such State ownership would be a deterrent to search by private individuals, who would otherwise be willing to risk heavy outlay on the chance of proportionate remuneration, whilst similar speculative action on the part of the State would be held reprehensible. Leaseholders would in any case carry forward minor exploratory work, but new and distant regions, such, for instance, as the Kent coalfield, would not be discovered, whilst the eastward development of the Yorkshire-Nottinghamshire field, concealed beneath thick post-Carboniferous deposits, would, under such conditions, have progressed far more slowly, and only by pressure of exhaustion of the more easily accessible western side. The question of the advisability of the State embarking in the commercial exploitation of mineral is a side issue, not involved in the general principle of proprietorship, and need not here be considered: whether such

operations are undertaken by the State directly, or through the agency of lessees, is a minor matter of merely administrative detail.

The greater question concerns known or probable accumulations of valuable mineral not utilised by the proprietors; has not the right in such case lapsed by disuse? In such cases as the Yorkshire-Notts coal-field, the great depth at which the prize seam (the Top Hard or Barnsley Coal) lies at the most easterly point of its proved existence, inside of Lincolnshire, involves such expenditure that exploitation must, apart from existing conditions, be a work of time. Forfeiture of right under such condition would be hard upon those who have expended much capital in test-boring. But what of that of adjacent proprietors, who have taken the arduous position of onlookers, with hands remaining in pockets? Should they retain proprietorship of the mineral, of the existence of which probably they were sceptical, till their neighbours proved it at their own cost?

The case is still stronger when the mineral concerned lies at, or close below, the surface, and has long been known to exist, although not used. Here there would be no such hardships as in the previously-cited instance: there has not been great, if any, exploratory outlay, and the diversion to the State of the ignored mining rights could not be regarded as injustice to anyone. Probably any legislative changes would be effected on a system of compromise, meeting half-way any rival claims between the State and the individual.

Local authorities have long held the right to raise road metal, &c., as needed, and the recognised principle of compulsory purchase for railways and other purposes of like general utility establishes an ample precedent for the supersession of private rights by public requirements. Nor is any logical discrimination possible between superficial and deep-seated mineral matter, every gradation existing between the two conditions, whilst although the economic result may be affected in some measure by the difference in amount of dead work between mining and open-cast operations, this is partially counterbalanced by the reduced surface required in judiciously-conducted mining.

Even should there not be found any such extensive accumulations of liquid petroleum as are anticipated by some enthusiastic investigators, there are assuredly vast bulks of rich oil-shale in the Kingdom, accessible at a minimum of outlay in respect of cost or time, and the sooner these are brought into use, the better will it be for the State and for the community generally, for everyone is affected by the shortage of hydrocarbons.

Twenty-Second General Meeting.

A meeting of the Institution of Petroleum Technologists was held at the house of the Royal Society of Arts, on Tuesday evening, 17th April, 1917, Mr. Charles Greenway (President) occupying the Chair.

The Members of the Council present were Mr. Herbert Barringer, Professor John Cadman, Mr. Andrew Campbell, Mr. E. H. Cunningham Craig, Mr. Arthur W. Eastlake, Dr. F. Mollwo Perkin and Sir Boverton Redwood, Bart.

Amongst the several lady visitors were Lady Slade (accompanied by Sir Edmond Slade) and Mrs. Greenway.

The President opened the meeting with the following address :—

Ladies and Gentlemen,

My first duty on occupying the Presidential Chair, which you have conferred upon me the very great honour of inviting me to fill, is the very pleasing one of moving a resolution of thanks to my gifted predecessor Professor Cadman.

It would be presumption on my part to attempt to describe his many qualities, his work in connection with Petroleum Technology, or the able manner in which he has furthered the objects which the founder of this Institution—our distinguished friend the "doyen" of Petroleum Scientists—had in view when he brought it into being; because all these facts are as well, or even better, known to you than they are to me.

But apart from the valuable services which the Professor has rendered in these directions, he is entitled to the gratitude and thanks of the public generally for the great services which he has rendered to his Country, not only in establishing at Birmingham University a means of providing young men with a course of scientific training in Petroleum Technology—from which source we shall no doubt in course of time be able to draw our own supply of experts for all branches of work connected with the petroleum industry, instead of having, as in the past, to rely largely upon other countries for such assistance—but also for the valuable work which has been done by him as Advisor on Petroleum to the Colonial Office and to the Government of Trinidad, and as an Advisor to His Majesty's Government in several other directions connected with the development of the petroleum resources of the Empire.

The importance of the petroleum industry to the civilised world develops with the course of years, but in this Country it is

so far only in its infancy. It is only now, as a lesson of this terrible war, that we are awakening to the fact that petroleum, and the securing of our own sources of supply of this valuable commodity, are a National necessity—not only for the great economic struggle which will certainly take place between the chief commercial nations after the conclusion of this War, but as a safeguard against this Country ever again being drawn into such a barbarous and destructive conflict as that in which we are now engaged. Until within the past few years, petroleum was only regarded as being of value for the production of artificial light, lubricating oils and wax; but later developments have shown that its greater value lies in what were formerly regarded merely as its by-products—benzene and fuel oil for motive power, solvents for a host of chemical and allied processes, dyestuffs in various manufactures, unguents in pharmacy, jellies and aromatic hydrocarbons for high explosives, etc., etc.—and it is, I think, no exaggeration to say that the demand for these so-called by-products, and the uses to which they will be put as time goes on, are practically illimitable. In view therefore of the very much greater part which petroleum is likely to play in the future history of the Nation than it has done in the past, it is, I think, a matter for which we have reason to be profoundly grateful that Sir Boverton Redwood should have conceived the idea of founding this Institution, and that his labours in the cause of Petroleum Technology should have been so ably and energetically seconded during the past year by my distinguished predecessor.

I will now ask Professor Cadman to allow me to express our very great appreciation of the services which have been rendered by him to the Institution with so much success and ability during his year of office as President—as well as those effected by him prior to that time, for I think I am correct in saying that he has from the outset contributed to a very large extent to the success of the Institution; and I will ask you, Ladies and Gentlemen, to accord to this recognition your very warmest support.

At the commencement of my year of office I would like to take the opportunity of expressing my full realisation of the very great honour which you have conferred upon me in electing me to the Presidential Chair, and my hope that I may be able to fulfil the duties of that post with satisfaction to you all and with benefit to the Institution.

When I was invited to accept the Chair for the current year I at first hesitated, because I felt that it would be presumption for me, a neophyte in the technology of petroleum,

to preside over an Institution of this highly scientific character, particularly in succession to two such distinguished scientists as Sir Boverton Redwood and Professor Cadman. These misgivings were in no way lessened by the thought that I should once a month for a period of eight months have to face, and to appear to be placing myself on the same plane of knowledge and scientific attainments as, the body of "savants" who so largely constitute the membership of this Institution, and whose acquaintance with the many scientific problems associated with the geology, production, chemistry, and refining of petroleum so far transcends any to which I can lay claim that, comparatively, I can only regard myself as a very humble student.

But after a good deal of consideration I came to the conclusion that I might accept the post with some advantage to the Institution and to the interests of Petroleum Technology, inasmuch as without co-operation of the commercial and financial experience to which I can lay some claim, the scientific knowledge and technical skill of the technological members of this Institution would be of little avail. The Institution was, as you all know, founded with the aim of promoting the co-ordination of the energies of the many classes of experts required for the successful development of the petroleum industry: scientists for the study of its many geological, mineralogical, chemical, physical and other problems; technologists for the examination and solution of the engineering, electrical, shipbuilding, and other problems which also continually arise in connection with so highly technical an industry as that of producing, transporting and refining petroleum; and financial and commercial experts for providing the capital and finding the most remunerative outlets for its various products. Each of these is necessary for the whole, and I therefore welcome the recognition which has been given to the financial and commercial side of the industry by the invitation which has been extended to me to occupy the Presidential Chair. I do so the more heartily because it has been long my feeling that the experts engaged in the technical work of oil Companies should be more closely associated with their administration than is unfortunately the case in most of the large British Companies at the present time. In all our other great British industries, without exception so far as my knowledge goes, the Boards responsible for the administration of Companies include at least one Director specially qualified to supervise the technical part of the businesses which they are conducting. Our great shipbuilding Companies, for example, have at least one practical shipbuilder on their Boards. Our

chemical Companies have at least one trained and highly qualified chemist. Our great engineering Companies have at least one practical engineer who has been specially educated and trained for his profession. Our spinning and weaving Companies in Lancashire have at least one practical spinner or weaver who has served his time in a mill, and learned his business thoroughly from selecting and preparing the raw cotton to the outturn of the manufactured cloth from the loom; and so on throughout the whole list of our industries. Even in oil, until within recent years, the practice was the same, for I think I am correct in saying that from the time of Dr. Young, the pioneer of the shale oil industry, it has been customary for the Scotch Companies to include one or more experts on their Directorate. But latterly it has become the fashion for oil Companies—as with South African mining concerns—to leave their administration entirely in the hands of financial magnates and company promoters who, however well they may understand the sciences of finance and company promoting, know absolutely nothing about the many technical matters on which the success of an oil Company so largely depends. In fact, were it not for the monopolistic character of the oil trade and the consequent certainty of profits for Companies which are in the fortunate position of being able to produce, refine, and distribute their oils, no matter how badly the technical branches of their business are directed, the system of administration which has hitherto been followed by some of the big oil Companies would, as it would certainly have done in the case of other technical industries which are more open to competition, long ago have led them to ruin.

This is all wrong, and I hope that this Institution may, by drawing greater attention to the many problems still awaiting solution in connection with the more economical and more extended utilisation of petroleum and of its many by-products, and to the consequent great importance of introducing more expert guidance and assistance into the administration of oil Companies, lead to the services of petroleum technologists being more largely availed of in an administrative capacity. It is true that the Companies I have referred to do already get the benefit of these services to some extent in a consultative or advisory form, but this does not suffice. As you are aware, in the conduct of a large oil business important decisions have at times to be made—often at very short notice—by Boards of Directors in regard to matters in connection with which technical guidance would be invaluable, but which necessarily, for reasons of competition, do not always permit of

reference to professional advisors whose services are available to the world at large, or to employés who may be with one Company to-day and with another a month hence. This is a difficulty which is much enhanced when the fields and refineries—and the technical men in charge of them—are situated thousands of miles away. In such cases the co-operation and assistance of technical Directors acquainted with the fields and refineries to be dealt with, and the particular conditions attaching to them, would often be of immense service, and I therefore hope to see the time when the appointment of at least one of such Directors for each branch of the business will be regarded as an essential for the successful administration of every British oil Company.

This Institution, after a life of only 3½ years, has already taken its place among the influential bodies to which the State is at the present juncture turning for counsel and research work. In view of this and of the much greater importance which the petroleum industry is likely to assume in the British Empire in the near future, I am very proud to be the President of a body of such great National importance—more particularly because I feel sure that it will assist very materially in securing for this country and for the Empire the position in the industry which her place as a leading commercial nation, and as one of the largest consumers of oil, entitles her; and I shall do my utmost to promote its aims, not only in the direction of bringing about co-operation and interchange of ideas among its members, but also in the further direction which I have indicated.

Prof. Cadman, in proposing a very hearty vote of thanks to the President for his interesting and instructive address, said he found himself in a very difficult position after the flattering way in which the President had referred to the work which had been done during his (Professor Cadman's) term of office. He was not entitled to the credit for the success of the past year: but the work of the Institution could not have been adequately carried on had it not been for the loyal way in which the Council had co-operated with him, and for the indefatigable efforts of Mr. Eastlake and Mr. Dalton. He felt in occupying the Presidential Chair that it was a sort of war-emergency office, and as the war had still no visible indication of ending, it was necessary that the normal work of the Institution should be resumed. The Council had been fortunate in securing the services of Mr. Greenway, a real live man, as our Trans-Atlantic cousins say, in whose hands the success of the year's operations would doubtless be secure.

The President's connection with the petroleum industry dated back a considerable number of years, and although much of his work might not have come prominently before the members it had been of great national importance. His connection with that great Company, the Anglo-Persian Oil Company, which had recently become so intimately concerned with the national needs and life of the country, fitted him for the highest distinction the Institution was able to offer. It was therefore exceedingly appropriate at the present moment that a man of Mr. Greenway's training, capacity and ability should occupy the Presidential Chair.

It was not permitted to him to introduce a discussion upon the President's address, and he therefore confined himself to expressing his appreciation of the very admirable and interesting remarks to which it had been their pleasure to listen, and it was his privilege to propose a hearty vote of thanks to Mr. Greenway for his address.

Sir Boverton Redwood, Bart., in seconding the motion, said that, as the immediate Past-President of the Institution had inferentially indicated, it was not customary to discuss the Presidential Address critically, but that did not preclude the members from expressing their appreciation of the character of the address which their new President had delivered, or their gratification at having induced him to accept the office. Moreover, even if the remarks which had fallen from Professor Cadman, or those to which he was asking the members to listen, were in a sense a little out of order, he claimed that there was ample justification for them in the fact that the present meeting was an epoch-making occasion, marking a departure from the ordinary procedure of scientific societies. Although the President, as many of the members were well aware, was a man who thoroughly understood the technology of petroleum, he was yet better known as a merchant. When the Institution was founded, it was the deliberate aim of those who took part in that action to create, if possible, what did not ordinarily exist in technical societies—a close co-ordination of the technical and commercial elements, the importance of which, he ventured to say, had become very much more evident during the past two years than it was three and a half years ago. Accordingly, in asking Mr. Greenway to accept the highest office which the Institution was in a position to offer, the Council had simply taken action in the direction indicated by the constitution to which he had referred. That the choice had been a wise one, would, he thought, be evident to all the members from the admirable tone of the President's Address; and he was sure the members would be equally satisfied that the Institution would derive great advantage from the

presence of Mr. Greenway in the Presidential Chair during his year of office. In addition, it seemed to him to be a happy coincidence that Mr. Greenway's induction to the Chair synchronized with the reading of a paper on the oil industry of Assam, an industry of some importance in that country, to which Mr. Greenway had for many years rendered services of high national value.

The Resolution of Thanks was put to the meeting by **Prof. Cadman**, and carried with acclamation.

The President, in reply, thanked Professor Cadman and Sir Boverton Redwood for the very flattering remarks they had made about him, and the members for the hearty way in which they had received them.

In inviting Mr. H. S. Maclean Jack to read the paper he had prepared on the "Development of the Petroleum Industry in Assam," he desired to say that the subject was one of particular interest to himself because he was, in a junior capacity, associated with Mr. Jack's father nearly forty years ago, when the Concession for the Assam Oilfields was obtained by Shaw, Finlayson & Co., of which firm he was then one of the senior partners, the predecessors of the firm of Shaw, Wallace & Co., of which he (the President) was now, in the fullness of time, one of the senior members. They all then had great hopes of the future of the Assam Oilfields, and he had since followed the history of their development with the greatest interest, but with some measure of disappointment that the results obtained had so far not fulfilled their earlier expectations. But, nevertheless, the knowledge which had since been gained of those fields, and of the continuation of the petroliferous belt which ran from Assam through Sylhet to the neighbourhood of Chittagong, gave every promise that at some future time that part of India would rank as one of the important petroleum producing centres of the world. Mr. Jack's account of the work which had been done there by the Assam Oil Company would therefore, he was sure, be of great interest to all the members.

The following paper was then read, illustrated by lantern-views, not here reproduced for lack of the requisite space:—

The Development of the Petroleum Industry in Assam.

By H. S. Maclean Jack, *Associate*.

I have been asked to write a paper for the Institution on the subject of the petroleum industry in Assam. It is just possible that some of you may have heard with a certain amount of surprise that there *is* a petroleum industry in Assam. Also many people at home,

and some in India too, have only a very vague idea of where Assam is, so I hope that you will agree with me that it is best to start from the very beginning of my subject.

Assam is in many ways the least known province in India. With the exception of the frontier provinces, it is the smallest in area and population of the main political divisions. It is situated in the extreme northeast corner of India, and is, therefore, as it were, rather off the main road of Indian life as a whole. Politically the province comprises the two valleys of the Brahmaputra and the Surma, and the hilly region separating them. Geographically the names Assam and the Assam Valley apply to that portion of the valley of the great River Brahmaputra which extends from about the point where the river issues from the Himalayas and turns westwards again, as far as the place where it makes its great bend to the south to flow into the Bay of Bengal.

Assam has had a more or less chequered history. In the past, under its own Rajahs, it successfully resisted the Mohammedan conquerors of the rest of Northern India, but later it lost its independence to the Burmese, from whom we took it in 1826. It passed through a time of exceptional publicity when, united to a portion of Eastern Bengal by Lord Curzon, it was elevated into a Lieutenant Governorship, and became the target of all the Bengali agitation. Later, as you will probably remember, the divisions were re-shuffled, and Assam returned to its state of a small province under a Chief Commissioner, in which it has since peacefully rested.

The northern side of the Assam Valley is the great mountain range of the Himalayas, and the valley extends eastward as far as that curiously interesting country where all the mountains and the rivers seem to have been twisted from a course running east and west to one running north and south, and where, I imagine, there are as many geographical and geological problems to be discussed as anywhere in the world. The eastern Himalayas are not so high as the rest of the range, but they are still something quite considerable, and I think there can hardly be a finer view than the range of snow-clad mountains extending nearly half-way round the horizon, which can be seen from very many places at the upper end of the Assam Valley. The southward hills are much lower, the main range only reaching an elevation of about 4,000 ft., and at the foot of these hills where they merge into the plain are many indications of the presence of petroleum. These indications continue not only in many places in the Assam Valley, but also reappear in the Surma Valley, and also, I believe, down the Arakan Coast. It would almost seem therefore, though perhaps it is not very wise to draw

these rather wild deductions, that these deposits may be in some way connected with the Burma deposits, and the very close similarity of the crude oils found supports this idea. In Burma of course the oil deposits have been known and worked for very many years, the Burmese themselves having established quite an industry before Europeans took the matter in hand. In Assam, however, which is much more thinly populated, and has such very different local conditions, the industry is a purely modern development.

The earliest reference to petroleum in these regions which I have been able to trace was made in the year 1828, soon after we took over the administration of the country. It was made by a Mr. C. A. Bruce, who had been sent by the Commissioner of what was then called the Northeast Frontier District to prospect for coal. The presence of indications of petroleum was mentioned several times in the next few years by various people: Major White in 1837, Captain Hannay in 1837 and again in 1845, and Captain Jenkins in 1838, all these references being, I believe, to indications of oil between Jaipur and Makum, somewhere along the line of the Dehing River, which flows westward along the foot of the Naga Hills. In 1865 Mr. H. B. Medlicott, who at that time was searching for coal in Assam, mentioned the oil springs of the Makum Pani, a tributary of the Dehing. Previous to this, however, a prospecting licence for petroleum had been granted in 1854 to a Mr. Wagentricher. The area was a very small one, only about 200 acres, and covered the shows at the Makum Pani and also at Bapoo Pung near Digboi. No work seems to have been done under this concession, and in 1865 a Mr. Goodenough, of the firm of McKillop, Stewart & Co., obtained another concession. This included the rights which had been given to Mr. Wagentricher and which had lapsed, but was for a very much more extensive area than the previous licence, covering some square miles. It might be interesting to mention that when this concession was granted, the then Lieutenant-Governor of Bengal remarked, that as there was no demand for oil in India, steps must be taken to put the Assam fields into a position to enable them to compete in Europe against the production of the United States.

A well drilled by hand was actually begun in 1866, and later a steam drilling-machine was used. Several wells were sunk, and from some a production seems to have been obtained. I think it must have been one of Mr. Goodenough's later wells which caused a mild sensation all over that part of the country. A steamer proceeding up the Dehing met what the imagination of the passengers thought to be a river of oil flowing down towards them. Many excited tales were told at that time of the enormous production

which had been obtained, though later experience leads one to think that the people were deceived by the spread of the oil on the surface of the water. What had actually happened was that oil had been struck quite close to the Makum Pani, a small tributary to the Dehing, and all the oil ran down the stream into the Dehing, and there spreading over the surface of the river covered the whole with a film of oil. It was still possible to see traces of this well when I was on the spot in 1911, thirty-five years later, and, as was pointed out to me, it was still actually producing oil, though hardly in commercial quantities.

In 1878 a Calcutta firm, Messrs. Shaw, Finlayson & Co., were granted a concession to build a railway, work coal mines, timber, and various other products, and in 1881 the Assam Railways & Trading Co. was promoted to take over these concessions. The records of previous explorers had, of course, directed the new Company's attention to the indications of petroleum which existed in their neighbourhood, and, needless to say, the possibilities of oil development occupied a good deal of their energies. In 1882 a concession was granted to the Company covering the petroleum rights over 30 square miles, all situated on the south bank of the Dehing, and included in the areas were the sites on which Mr. Goodenough had worked. Experimental drilling was carried on, but the activities of some of the Company's other departments called the attention of the management to the fact that at a place called Digboi, some nine or ten miles north of the Makum concession, there were indications of petroleum deposits which were more numerous and pronounced than those at Makum. In 1892 a concession for this area was obtained, and the first well was drilled in 1893.

Six years later, in 1899, the Assam Railways & Trading Co. promoted another Company, which was called the Assam Oil Co., to take over the whole of its petroleum interests, and handed over to it the Makum and Digboi concessions. The new Company established its headquarters at Digboi, which field had been found to be the more important of the two. It also took over their rights from a Syndicate which had been working in the same neighbourhood. I might add that the Assam Railways & Trading Co. did not entirely relinquish their interest in oil, as they took a very large number of shares in the new Company, and the two Boards are intimately connected, so that the continuity of interest and management has really remained unbroken from the beginning until now.

As to other areas, surface indications of petroleum occur very frequently all along the foot of the hills, but no other petroleum

deposits are being worked in the Assam Valley. In the Surma Valley a certain amount of drilling has been done, and in one instance, at least, with successful results. The Assam Oil Co., however, is the only company which is producing oil, refining, and marketing it, and the history of the development of the petroleum industry in Assam is up to the present practically the history of the Assam Oil Co.

Now, in order that you may appreciate some of the difficulties which had to be faced by the Company's pioneers, I will attempt to give you some description of the district in which they have to work. The whole of the eastern end of the Assam Valley, except where clearances have been made for cultivation, is covered with extraordinarily thick jungle. Here the jungle consists of trees which vary from 100 to 120 ft. in height, and the ground underneath is usually covered with a very close undergrowth, through which it sometimes is difficult for even an elephant to penetrate. In this respect the surface of the petroleum area presents the greatest possible contrast to its nearest neighbour, that is, the Burma field at Yenangyoung. I hope to show you some slides presently which will give you an idea of the conditions.

Of the two areas which have been actually worked by the Company, the southern one, known as the Makum area, is the one on the bank of the Dehing, to which I have made several references before. It is the one which first caught the eye of the early explorers, as, being conveniently near the river, it was the more easily reached. It lies on a slightly elevated plateau between the northernmost of the Naga Hills and the river, the distance between the two being about three miles. The ground is on the whole level, but a good deal broken towards the hills. The actual extent of the grant is four square miles, but there are indications of oil in many places outside.

The other area, which is called the Digboi field, lies about nine or ten miles to the north, where a small range of hills crosses the otherwise absolutely flat valley of the Brahmaputra. This range appears to be a continuation of a spur of the Naga Hills, which branches off in a northeasterly direction near Jaipur. At Digboi there are steep hillocks, 40 to 50 ft. high, placed very close together. Digboi is at the very end of this small range. Farther to the east the hills die away and disappear altogether.

One of the first things which a pioneer of a petroleum industry has to do is to get that minimum of geological information which will enable him to select sites for a few wells, and which later will be developed into a system on which he will work the whole area.

For several reasons the collection of any geological information in these districts is very difficult. The ground is so thickly clad with jungle growth, weather products and alluvial accumulations that observation is much hindered; the exposures of rock are few and imperfect, and in many cases almost useless, as the sandstones are of a kind in which joint-planes and false-bedding directions cannot always be distinguished from the planes of true stratification; movement is slow and difficult, and is almost entirely confined to the few paths and streams, and when satisfactory exposures are found, the lack of character in the rocks makes identification uncertain.

The first wells, therefore, were inevitably drilled blindly, and I am afraid we must attribute the fact that so few of them were failures more to good luck than to the almost superhuman foresight which would have been required to ensure success. Surface shows were, of course, the chief guide, and in Assam these surface shows take what I believe to be rather a peculiar form. All through the jungle in the neighbourhood are places which are locally known as "pungs." They are open spaces in the jungle to which the wild animals resort. I am told that the furred animals lick the soil, whilst elephants, buffaloes and such-like roll in the mud which they have churned up by trampling. In a recent report it was mentioned that the animals actually eat the mud, but this I can hardly accept. Every one of these pungs is in some way connected with surface shows of oil. Oil is always traceable somewhere close at hand; there are usually exposures of rock, and, besides actual oil seepages, there are very often fairly strong blowers of gas. I will leave it to others to suggest why the animals congregate in these places, but so that you may realise the number who actually do go, I might tell you that at Namchik, one of the largest of the pungs, there are numerous paths all kept just as clean and beaten as any path over one of the commons round London, and made entirely by wild animals. On one side of the pung are some sandstone rocks, and some of the paths lead through gaps in these. The gaps are very narrow, and the rock on each side has acquired a surface-polish from the constant passage. Whatever may be the reason for which the animals resort to the pung, we can take it for granted that it does them good, and perhaps one can assume that it is merely another instance of the universal benefits which are conferred on all sides by the uses of petroleum.

But to return to the difficulties met in trying to obtain geological data, a steady and continuous search over years has produced a volume of evidence for consideration. Each point has been tested

and considered, and in time, rejecting some and accepting others, the preliminary problems have, I think, been solved, and it is hoped that a stage has now been reached at which the sites of the wells can be selected with some certainty. It may appear to you, and quite naturally, that a very long time has elapsed before arriving even at the modest result claimed. But if you will bear in mind all I have told you regarding the conditions of the country itself; that the work was being done in a new territory, with absolutely no previous geological knowledge or experience to guide those in control; the confusion which followed from different drillers deciding to call the same strata by different names, and with equal impartiality different strata by the same names; and also the slowness with which in consequence the data gathered by research and from drilling results was collected, you will, I think, appreciate the position.

The strata which are found on the fields consist of hard shales and clays of various sorts, including bands of a very soft spongy nature, and sandstone of all degrees of hardness. The beds usually dip at a sharp angle. The dip on one flank of the anticline is usually very much steeper than the other, in some cases being perpendicular, and sometimes it is actually overfolded.

In order that you may understand clearly the progress which has been made in the arrangement and equipment of the drillery, I think I will describe to you the condition of the fields at three different periods. All the original drillers employed by the Company were Canadians, who used the Canadian pole system. Difficulties of drilling are, I suppose, of the same general nature all the world over, but the particular ones which were emphasised in Assam, and gave the most trouble, were the bands of spongy clay and the steep dip of the strata. Owing to the latter, when the drill suddenly came on a bed of very hard rock, it was very easy to get the hole out of the perpendicular. In that contingency, the soft clays clasped the casing, making it an extremely arduous task to get through even 20 or 30 ft. It was necessary to "work" the casing so frequently that sometimes it almost seemed that there was no time for drilling. The method of meeting the difficulty which was most in favour with some drillers was to let the first string of casing go, and insert another. By this means the bands of clay were passed indeed, but often at the cost of not getting deep enough, or, when the oil was reached, the diameter of the last string was so small as to be hardly worth the cost.

The ordinary wells took an extremely long time to drill, and were

very expensive as well; but time was, of the two factors, the one which we could least afford to lose. And, at this time, to drill an out-well, by which I mean an experimental well away from the main field, was almost unbearably slow. The only communication between the well and the main settlement was by elephant. All supplies, tools and casing for the well, coal for the boilers, everything had to be carried out by elephant to the site. If weather conditions interrupted supplies, which they frequently did, and coal ran short, wood had to be used, which merely gave out plenty of smoke and no heat.

For half the year working in the jungle was very unhealthy, and frequent sick leave had to be allowed for in all calculations. But time in proving territory, time in getting results, was of the very greatest importance. The work was being carried out for an ordinary commercial Company, and shareholders are never anxious to obtain results for their grandchildren, but desire dividends for themselves—and do not hesitate to say so.

The better results which were immediately wanted could only be obtained by improved methods and more plant; more plant meant the expenditure of more money, and no more money could be obtained until improved results were shown; thus completing the vicious circle in which affairs had become entangled. However, it was obvious that extensive changes were necessary, and the Company had to try to do what little their means allowed, partly by small increases in plant, but chiefly by improvements in methods. It was not easy, though, to get any new methods introduced, as the ordinary driller at that time was not a man who accepted suggestions gladly. The first actual alteration made was the sending out of a water-flush plant made by an Austrian firm styled Albert Fauck & Co. When it arrived on the field it was condemned by the drillers then in charge as being too small and altogether too weak for any effective work.

However, the reorganisation which was imperative was gradually pushed on with and completed, and the drillery arrived in due course at what I might term the second stage. At that stage the professional driller from Canada had been almost entirely dispensed with, though occasionally one or two were engaged for some special job, and the field was in the charge of engineers who had acquired the whole of their experience of drilling in the Company's service. They acted as supervisors, and natives who had also been trained on the company's fields were in actual charge of the wells. These natives were of various races, and they have shown themselves quite as efficient as the Canadian drillers, and the Company

has several now whom it would unhesitatingly employ on out-work without any European control.

As to plant, ropes were substituted for the Canadian poles. The ordinary manila rope used in America was not adopted, but experiments were made with steel wire-rope, and with a reasonable amount of success from the very first. After a few trials with different "lays" and "makes" a rope was chosen which for some years now has given every satisfaction. Also there was a general strengthening up and improvement of tools and other details all round. Then a very great effort was made to avoid the trouble which I have already mentioned, carrying each string of casing to the greatest possible depth, and this was fairly successful. But at first it only brought another trouble in its train, as it was found that the 7-in and 8-in. casings, which were attaining depths they had never done before, were not strong enough. They took to collapsing suddenly, and on one or two occasions a well was lost in this way. After some theorising, the practical solution of thickening the walls was adopted, with satisfactory results. Also in order to facilitate the drilling of new wells away from the main field, the directors decided that for the future the construction of a railway line was always to precede the actual work of proving a new area, thereby ensuring that a proper service of supplies could be kept up.

Another alteration made was to send out steel rigs and derricks from this side. Previously the rigs had been made of timber cut on the spot, but timber in Assam is never very satisfactory, and the longer the well took to drill, the greater the chance of the whole thing coming down on the driller's head before he had finished, which it actually did on very many occasions. Quite apart from any other difficulties which might result when the derrick collapsed, by the time another had been built, the casing of course had set fast, and one of the things it was most wished to avoid had occurred. The new rigs were designed by the General Manager, and though perhaps they are slightly on the heavy side—certainly they are as compared with similar American derricks—they have done excellent work and stood up to every demand made on them.

All these improvements combined enabled a well to be sunk with reasonable certainty and of satisfactory diameter in about one-third of the time which it had previously taken, an advance which did great credit to the staff, and which I think they were entitled to regard with considerable satisfaction. And I should like to repeat that both the European and native staff were men who, with the exception of the Field Manager, who had made occasional visits to Burma, were trained entirely on the Company's own field, and

had never seen drilling methods elsewhere. The results they were competing with were those obtained by trained Canadian drillers working with tools, plant and methods of their own selection. In a few years and in every branch matters had been improved out of all recognition.

Naturally, the Company was not entirely contented even with this, and, selecting the clays as the strata which gave the most difficulty in drilling, sought to find a remedy for them; and this brings me to the third stage of the drillery development. A Parker rotary plant was sent out with American drillers in charge, and this plant has been a complete success—in fact, the Company have increased it recently. The rotary can deal with clay with the greatest possible ease. But the interspersed sandstones, which up to then had been treated almost with contempt—that is, the drillers used to look forward to getting into the sandstones in order to make headway with reasonable speed and a minimum of trouble—gave everyone an unexpected surprise. All these things were comparative, and it was certainly the impression that what was called "rock" in Assam was really something almost soft. The American drillers now say that it is some of the hardest they have ever encountered. The ideal for work in Assam is undoubtedly to use the rotary for the soft strata and the percussion system for the hard; but we have not yet evolved a satisfactory combination rig for this purpose, and the average progress made by the rotary is so good that it is certainly not at present an urgent necessity to deal with the problem.

The present position is that both rotary and percussion drills are going. The fastest drilling the Company has yet done with the rotary is 500 ft. in four working days; the slowest marked was 1 ft. in ten hours. With the percussion system, about the most ever done in one day was 40 ft., and 20 ft. to 25 ft. a day was considered good progress—in fact, that would be an average which was seldom maintained. In attempting to get through clay beds, very often the advance for a fortnight would only be about 20 ft. It may also be interesting to mention that when both the American drillers who went out with the original rig left at the end of their agreement, the rotary was worked by the native staff, and equally good progress was made. One well under a native has actually done over 100 ft. in a day. One of the Americans has, I may mention, since rejoined, and is supervising the work of the natives who are actually in charge of the rigs.

I have now dealt with all the preliminary work, and have arrived at the point where in a logical sequence I should describe the actual oil obtained. The crude petroleum in Assam is found

in intermittent deposits situated in loose sands. Considerable gas pressures are present, and on first striking the oil the well usually flows with a good deal of force. In most cases it will continue to blow at intervals for many months, and it is not until the well has reached a mature age that pumping is necessary. As an example of the gas pressure, recently when oil was struck at a depth of about 900 ft., in a well being drilled by the rotary, the whole of the column of mud in the hole, together with all the tools, was blown out, and the well flowed for some little time.

No one of the Company's wells has proved to be a really heavy producer, and according to the theories which have been formed, the field is not likely to provide any big gushers, but we are quite willing to have this theory falsified. On the other hand, the wells are very good stayers, and remain reasonable producers for a comparatively long period. When the oil reaches the surface, it brings with it a considerable proportion of sand, and one of the natural constituents of the oil is a heavy percentage of wax of a very high melting-point. As one might expect, therefore, the wax and sand combine to choke the well, and at fairly frequent intervals form a very hard plug. A special gang is kept constantly at work cleaning the wells as they choke, and keeping them generally in order.

The pure crude is ·856 sp. gr., appears of a very dark brown, almost black colour, by reflected light, without the fluorescent greenish tint common to many American oils. By transmitted light at 84° F. the colour is warm sienna, and the oil is quite transparent, and free from suspended particles of extraneous insoluble matter. If the oil is allowed to evaporate spontaneously on a microscope slide, under favourable conditions as to temperature, a half-inch objective shows no distinct crystals, but by the use of an 8-in. objective clusters of very minute lamelliform crystals, some foreign substances, and what appear to be parts of organic structures, become distinctly visible, embedded in a transparent yellow oil. The oil is perfectly fluid at 82° F., but at 81° F. crystals of paraffin begin to form, and settle. These crystals are separate and defined; they do not agglomerate into a solid cake, but can be easily diffused through the oil by slight agitation. At 77° F. the oil loses fluidity and becomes semi-solid.

I do not think that there is anything exceptional about the methods of distillation. The system used has been worked out and evolved by the management in practice as the system best suited to the crude oil, and to the Company's particular requirements. Owing to the distance of the refinery from all sources of supply, and the consequent heavy cost of imported chemicals, it has been

of the greatest importance to reduce the use of cleansing and other agents to a minimum, and the whole process is actually carried out simply by careful distillation and cuts at the worm end. The crude oil, after having been pumped from the drillery, is settled in tanks, from which it is pumped into boiler stills arranged in groups of three. In the boiler stills the distillation is continuous. From the first still crude benzene is taken off, about 750°–770° ; from the second still intermediate kerosene, and from the third the bulk of the ordinary kerosene. The residue is distilled to dryness in pot stills, and in these a continuous feed is not usually resorted to. The distillate from the pot stills starts and finishes a very bad colour, and these portions are cut out and re-distilled later. The whole of the middle distillate is passed through the refrigerating plant. The plant has both an anhydrous ammonia machine and carbonic acid machines, and in practice it has been found best to pass the oil through both in succession. From the former is obtained the bulk of the wax of high melting-point, and from the latter the basis of the batching oil. Batching oil, I may say, is oil used for softening jute fibre in the process of manufacture.

The range of products is as follows:—the non-condensible vapours are conveyed from the worm ends to the furnaces, and used as fuel. The crude benzene obtained from the boiler stills is re-distilled in closed steam coils, and two qualities of petroleum spirit are produced, having specific gravities of ·710 and ·750. It could be wished that the demand for spirit were very much greater than it is at present, as it does not absorb the supplies available. There is the usual consumption for motors, but in India this is small. In order to stimulate sales, the Company has taken a considerable amount of trouble in developing a demand for lighting, the system used being the conversion of the spirit into vapour, to be burnt with an incandescent mantle in the manner probably well-known to all of you. The efforts in this direction have been fairly successful.

The intermediate kerosene from the second boiler still is a colourless distillate, and gives an oil of very great power value in internal-combustion engines when slightly concentrated. A small quantity of water-white kerosene is produced for Europeans, but the great bulk of the kerosene product is absorbed by native consumption. It is a low-grade oil of about the colour of whisky, and smokes abundantly when burnt. Luckily the native consumer regards this as rather an attraction than otherwise. This tendency is attributed to the presence of the aromatic hydrocarbons.

Our batching oil is concentrated to ·885°–·890° sp. gr. Very

great trouble was experienced in hitting off the best method of getting this important product, and for many years the refinery was not successful in making anything suitable. Even now in appearance the oil differs very considerably from others which are sold. But in use it is understood to give very excellent results, which is the main thing.

Paraffin wax is one of the most important constituents of Assam petroleum, which resembles in this respect most of the Eastern oils. It is a hard wax of very high melting-point, and the percentage in the crude is considerable. The melting-point adopted as a standard is 135° F., but during the greater part of the year the difficulty is to obtain the softer waxes to blend down to this average. A melting-point of 140° is quite normal for a run of wax: and when required for exhibition purposes, or something similar, wax of a melting-point of 145° and higher has been produced with no difficulty whatever. It is customary for the Company to market the wax in a semi-refined state—a bright lemon-yellow in colour.

When distillation has been finished, 8 to 12 in. of coke is found in the pot still. This coke is 97–98 % pure carbon, and at present it has to be used as fuel under the stills. It would prove a marketable product, I believe, if only the refinery were situated elsewhere; but under present conditions the freights to be paid are against it, and make the selling impossible. The Refinery Management by careful methods have succeeded in reducing the waste in distillation to about 5 % of the crude, which I think is a result reflecting great credit on them.

As to distribution, the only pipe-lines we have are those actually on the drillery itself, and from the drillery to the refinery, all quite short distances. The refined products are moved in tins, drums, or in bulk on the railways, and the batching oil for Calcutta is taken down the river in bulk flats.

Well, we have now gone systematically from the first notices of oil in Assam, through the preliminary drilling difficulties, up to the results which are at present obtained in the refinery. Eighteen years ago, though the Assam Railways & Trading Co. had an experimental refinery and was testing the best methods of dealing with the crude, it may be said that, from a practical point of view, no oils were being produced in Assam. The local production now supplies the whole of the Assam Valley with its wants of kerosene and also helps to supply some of the most thickly populated districts in Eastern Bengal. The petroleum spirit is known all through the North of India, and the Company takes a creditable share in the supplies of batching oil for the

Calcutta jute market—the largest, I believe, in the world. The Assam paraffin wax is exported to all parts, and whilst it shares to the full the high qualities characteristic of most Eastern waxes, for one or two purposes it is preferred by users to any other.

As to the future, the Company of course is not content to rest on the results which have been obtained up to now. The developments on the present fields are pushed on with energy, and careful exploration and search is being made in the neighbouring districts. It is expected that areas will thus be provided for future work. It must, of course, be admitted that as yet Assam plays only a very small part in the whole petroleum industry, but there are those connected with the Company who are sanguine enough to hope that in time there will be developed in Assam an asset which will be of very much more than merely provincial importance.

No paper on the development of petroleum in Assam would be complete without references to Sir Boverton Redwood, who has acted for very many years past as the Company's Technical Adviser, and whose resourceful mind and unique knowledge of petroleum technology have always been at their disposal to meet the various practical difficulties which have arisen; to Sir Thomas Holland, who as Geologist to the Company has evolved the working theories of the fields, and now advises on their proper development; and to the General Manager, Mr. A. B. Hawkins. Mr. Hawkins has been the chief official of the Company for the last thirteen years, and during the whole of that time the sole management of local affairs has been in his hands. He has not only interpreted and given effect to the policy and instructions of the Directors, but has himself initiated and carried out improvements both in the refinery and the drillery, and a large measure of the credit for whatever success the Company has attained is due to him for the energy and intelligence with which he has performed his duties.

DISCUSSION.

The President thought the members were very much indebted to the author for his extremely interesting paper. The author rather diffidently suggested that there might be some connection between the Assam oil deposits and those of Burma. Although he (the President) did not claim to be an authority on the subject, he was inclined to go very much further, and to suggest a connection between those fields and the Russian oilfields, and even with those of Rumania and Galicia, in the north, and those of Java, Borneo, Sumatra, and New Guinea in the south; for there was an almost

unbroken oil belt running south-east from the European oilfields he had mentioned, through the Caucasus, Persia, Baluchistan, the Himalayas, Assam, Burma, and the Straits, to the Australasian Archipelago. As he had previously stated, he did not claim any special knowledge on the subject, but it appeared to his lay mind that there was an undoubted association between those fields, and that in them there would be found in the future the largest sources of supply of any existing in the world. However, that was a question regarding which he would like to hear the views of the geological members.

With regard to the comparatively small progress which had so far been made in the development of the Assam Oilfields, the author had explained the great difficulties which his Company and these had encountered, which all the members could well appreciate, but he ventured to suggest that not the least of the difficulties had been insufficient capital expenditure at the outset on exploration and testing work. The great cost of work of this nature in countries such as the author had described, was well known, and when he (the President) mentioned that Mr. W. K. D'Arcy spent £300,000 on his exploration and testing work in Persia, and the Burmah Oil Company another £150,000 before the rich fields which the Anglo-Persian Company were now working were proved, although the whole country from the Caucasus in the northwest to the Mekran coast in the southeast was teeming with oil springs and other indications, it would give some idea of the amount of money which, in countries of that difficult nature, had sometimes to be expended before full success could be achieved. In making that statement he desired to qualify what he had said about Persia to some extent by explaining that at an earlier stage another equally prolific field was found, but at too remote a distance from the coast to be then commercially workable, although it would no doubt be opened out before many years were over, now that there was a prospect of railway construction being undertaken in Persia at an early date. It was also known that large sums of money had been expended in Trinidad, where the conditions were perhaps more comparable to Assam, without so far fully proving the extent and value of the petroleum deposits on that island. But in Persia, after once striking the fields to which he had referred, other equally rich fields were being met with from time to time in what he might almost describe as embarrassing profusion, for it would take many years before all of them could be opened up. That, he ventured to predict, was what would happen in Assam and in Sylhet, when once the geological examination of the petroliferous country in those provinces was

more thoroughly taken in hand, because that part of the British Empire unquestionably contained extensive and rich deposits of petroleum, which only needed the expenditure of more money to be located and developed. One point which the author had omitted to refer to at all in his description of the work in Assam was the depth to which the wells had been carried, and if the author could give that information, without disclosing any secrets, he thought it would be of the greatest interest to the members.

Sir Boverton Redwood, Bart., in opening the discussion, thought the members would agree that the author was to be congratulated on having given the Institution a most interesting account of a little known section of the great petroleum industry. In the light of his special experience, obtained during frequent visits to the country, and by the aid of the beautiful photographs which had been shown, he had given a vivid conception of the exceptional difficulties attending pioneer petroleum development in a tropical jungle. In view of the store of information which had been obtained from the work carried out, he did not think that the author need feel any dissatisfaction with the results obtained, having regard to the comparatively small amount of financial support which had been available. No doubt both the author and his father before him would have been able to point to a fuller record of commercial achievement if they had had the measure of support in the shape of money to which the President had alluded. He believed it was almost exactly to a day, 27 years ago, that, in a paper read before the Society of Chemical Industry on the Oilfields of India, he gave some account of the petroleum development in Assam. He remembered that the late Dr. J. Berry White, a director of the Assam Railways and Trading Company, who had at that time just returned from a visit to Assam, was among those who took part in the discussion, and expressed confident anticipations in regard to the future of the industry, which, as far as circumstances permitted, had been realised. There was a note of sadness in the thought that it was only quite recently that another pioneer in the Assam oil industry, the father of the author of the paper that had been read, passed away. He regretted that Mr. Evan Jack had not been spared to have the gratification of noting the able manner in which his son responded to the invitation extended to him by the Council of the Institution.

A regular attendant at the meetings of the Institution, in the person of the Honorary Librarian and Editor, Mr. W. H. Dalton, was absent through illness, but had sent the following communication to be read at the meeting.

Mr. W. H. Dalton wrote as follows:—

I should like to offer a suggestion on the collateral point of the resort of wild animals to the pungs: that the principal attraction lies in the salt water and efflorescences of salt. The "licks" of Kentucky are famous for the hundreds of skeletons of victims mired in the treacherous slime, including many of the gigantic mastodon. Some five or six years ago, the body of a rhinoceros was found at Starunia, Galicia, converted into a natural mummy by the deposit of ozokerite which had engulfed it. In somewhat analogous conditions, whilst fleeing from the blazing oil-jets of Sodom, Lot's wife, looking behind her, fell into one of the many "slime pits" or asphalt pools, and became a pillar of salt, i.e. a prostrate column of bitumen.

It is quite conceivable also that the animals frequenting the pungs find relief from the attacks of insects, not only whilst rolling in the mud, but subsequently by its caking upon their skins, whilst the oil would be a further deterrent to the pests, besides exercising a therapeutic action on dermal diseases and on wounds acquired in the jungle.

Mr. Cunningham Craig said he was afraid that if he once began to talk about the geology of Assam he would occupy the time of the members so long that their patience would be exhausted before he had really gone deeply into the subject. He had known for a very long time from one of the earliest shareholders of the Assam Petroleum Company, Sir Robert Christieson, of the troubles experienced by that Company. Sir Robert had told him many a time of the difficulties that had to be faced when operations commenced, but the Company had triumphantly come through so many great difficulties, which had been explained so clearly by the author, that he was sure all the members desired to wish it a future of still increasing prosperity. In continuation of Mr. Dalton's communication, he desired to refer to the wonderful way in which what human beings were accustomed to call the lower animals found out things of real value and interest for themselves before we discovered anything about them. For instance, the Sinclair hot springs in the Columbia Valley, in British Columbia, the strongest radium waters in the world, were discovered through the black bears. These astute animals, on leaving the winter quarters where they had been hibernating, were in the habit of going to the hot springs in the limestone rock to, as it was called, "limber themselves up." Since the springs had been utilised more by human beings, bears were not so often seen there; and he believed they would have a very great future before them as a source of radium water. But they were

discovered originally by bears, then by the Indians, and shortly it was to be hoped they would be discovered by the invalids in this country who had in the past been accustomed to go to Germany for their cures.

Dr. F. M. Perkin referred to the very high melting-point of the Assam wax, and its suitability for the manufacture of candles for tropical climates.

Mr. A. MacDougall, referring to the impasse as to increase of capital and improvement in results, said that it appeared that Assam afforded every prospect for the development of a large and valuable oilfield, which extended possibly into the Naga country. Facilities were evidently required for bringing that oil down in pipe-lines, to erect which capital would be required. He desired to ask why the Government of India had not encouraged and supported the industry by supplying capital for the development of such a promising undertaking. He was sure those connected with the Company would have been the first to welcome such encouragement, because it was essential that the interests of the country should be absolutely in British hands, for reasons which had become so apparent since the War commenced. He desired to ask why the support given by the Government of India had not been more liberal, if it had been given at all.

Prof. Cadman expressed his pleasure at having heard the author's interesting paper, because it would contribute very largely to the interest of the *Journal*, in that it contained a record from the earliest date of what he hoped might be a very important oilfield in the future. He could not refrain from referring to that portion of the paper which directed attention to the tale of experience concerning the various machines which had been applied in drilling. Almost every conceivable rig or drill that it was possible to use on an oilfield seemed to have been experimented with. That directed attention to a point which he hoped in the future would be very much more seriously considered, namely, the procedure that should be adopted in drilling through rocks, the nature of which could be determined by a thorough geological examination prior to drilling. If an oilfield was tested by a process of elimination of the various drills and machines which could not be successfully used, a conclusion would ultimately be reached, as the author stated in his very careful remarks, that for particular classes of rocks a particular form of drill should be used. He ventured, however, to suggest that by a proper technical examination of the problem it should be possible to select the most efficient tools for the work, the type of rock which had to be pierced having

been carefully considered previously. The paper was from that point of view of considerable importance, in that it referred to a tale of experience by no means singular in the past, but which in the future he ventured to hope would not have to be told in such a lamentable strain. He was sure the members desired to congratulate the author upon having put forward a very interesting account of an important oil development in Assam.

Mr. W. J. A. Butterfield, referring to the decision as to railway-construction preceding the drilling of "out" wells, asked if that meant ordinary railway tracks laid on the ground, or whether aerial or rope railways were used, because it seemed to him that, in view of the nature of the country which had been shown on the lantern slides, overhead lines possessed great advantages from the point of view of cheapness in dealing with pioneer work in outlying districts. He was not referring to the main track for getting away the large tank wagons, but only to lines to the outlying fields.

Mr. H. S. Maclean Jack, in reply, said he sincerely hoped that the paper had to an extent conveyed to the members the interest which he felt properly belonged to the subject with which it dealt. If they could see for themselves the contrast which the settlement and refinery at Digboi presented to the surrounding conditions, they would obtain some idea of what was in his mind. The change within a few yards from the primeval forest, which had remainded practically untouched for untold ages, to the absolutely modern refinery, lighted throughout by electric light, and full of complicated machinery, could hardly fail to impress the members. The same contrast was apparent in all work in Assam, and added greatly to the interest of the problems which had to be dealt with.

In answer to the various questions that had been asked, in the the first place, the depth at which oil was obtained varied a great deal. As he had stated in the paper, the deposits were intermittent. In one well they obtained what they roughly classified as their first oil, while in the neighbouring well they might miss it altogether. Speaking broadly, there were three zones from which the oil was got; they might be roughly placed at 1,000 ft., 1,500 ft. and 2,000 ft. The deepest well the Company ever sank was 2,500 ft., and in that case not a drop of oil was seen from the top to the bottom.

If drilling tools could be standardised, as had been suggested by Prof. Cadman, it would be of the greatest value to everybody. But when business people started an oilfield, they necessarily applied to the technical driller for help, and he had never yet met a driller who would not promise him at once that he could drill through anything, and in the shortest possible time. Also the

opinions of the different men seemed to vary considerably on the means to be used, and it was this inherent optimism, combined with the differences of opinion, which involved so much initial difficulty. If it was possible to have some sort of exact system by means of which both the strata and the tools to deal with them were classified, it would very much simplify the work from every point of view.

The President had referred to the question of capital. He quite agreed with Mr. Greenway that the expenditure of large sums of money in proving the territories was not only of the first importance immediately, but a very great help at later stages. But the President had mentioned spending between £400,000 and £500,000 on prospecting in Persia. The total capital of the Assam Company was only £400,000, so that they would not have had much left if they had adopted anything like that standard in their prospecting. In answer to another question, the Government of India were extremely good landlords: he had nothing to say against them from that point of view, but they had never offered to provide the Company with any money. Except in the case of railways, he understood it was not their policy to provide capital for commercial enterprises. In reply to Mr. Butterfield, he said that the railways to which he referred were metre gauge railways, built in the ordinary way. The Company experimented at one time with an overhead type of line, but it was not a great success. Whether that was due to the fault of the Company or to the fault of the system, he would not like to say. One difficulty experienced was that such a railway did not carry enough weight. Most of the machinery which had to be sent out to the oilfields was very heavy, and the Company found that it was impossible with an aerial railway to deal with it in sufficient quantities. It must also be borne in mind that, when the oil was obtained, the railway was there to convey it, by means of tank wagons. Later on, of course, a pipe-line could be laid, but at first the railway proved exceedingly useful.

The President said that a number of very interesting points had been raised by the various speakers. The author had suggested that railways were a necessity for, or at any rate a very desirable aid to, outside test drilling in Assam. This suggestion was a somewhat remarkable one, and he would like to point out that if the Anglo-Persian Oil Company had waited for the construction of railways before drilling wells in Persia, they would never have drilled any wells there at all. At any rate, probably there would not have been any wells drilled there for the next fifty years, because

railways do not exist in that country. He imagined a company must have a superabundance of capital if it could afford to indulge in what he might almost call the luxury of building railways for exploratory work. He thought the whole trend of the discussion brought them back to the point he mentioned in his opening remarks, viz., that the reason Assam had not been developed more than it had been at the present day was insufficiency of capital expenditure on geological and testing work. Whether or not the Indian Government should have helped the Assam Oil Company out of that difficulty was a matter which it was hardly within the province of the Institution to discuss. As he had previously stated, he has been acquainted with the Assam Oil Concession for nearly forty years, and he had always possessed the very strong belief that Assam would play a great part in the future of the oil trade of the world. It had been a very great disappointment to him that the progress there had so far been so small, and he hoped that the necessary capital for its proper development would before long be forthcoming. He had been over a portion of the country himself, and had been struck by the marvellous oil indications that prevailed everywhere throughout the country. Priests were to be found in different districts sitting over oil-gas fires that had, according to the local belief, been burning from time immemorial. Exactly the same indications appeared in Persia and Baku; in fact, the Baku oilfield owed its discovery, it was believed, to the presence of a fire temple which was supposed to have been in existence for hundreds of years, in which the petroleum gas had been burning during the whole of that time. The conditions were so similar in Assam, in Persia and in Baku, that he could not help thinking that the origin of the reservoirs of oil from which those enormous supplies of oil came was the same in each case, and he therefore was still, and always would remain, a very strong believer in the future of Assam. He concluded by asking the members to accord a very hearty vote of thanks to Mr. Jack for the interesting and able paper he had read.

The resolution of thanks was carried by acclamation, and the meeting terminated.

The following communications were subsequently received :—

(1) By **Mr. M. A. Ockenden.**

Mr. Jack's description of the difficulties experienced by the early well drillers in Assam is interesting and instructive. The first well drilled in any new district, especially in a virgin country —as Assam—must necessarily be carried out cautiously. Even in a country with every convenience of transport, labour, tools, etc., the first borehole is usually expensive. The slow process

of drilling the first well tends to "freeze" the pipe, as the clays swell, and the cavings settle behind the casing. There is also the use of tools unsuitable for geological conditions which have to be imagined in advance. Whatever system is adopted in the drilling of the first well usually produces mistakes or delays, owing to the over-cautious manner of drilling in order to obtain accurate geological information and every possible indication of gas or oil.

In using the Rotary system, Mr. Jack does not tell us if water-flush is used, as with the original Fauck tools, or a carefully prepared mud-mixture, as is customary with the use of the Rotary in other parts of the world. A proper proportion of mud consisting of pure clay, or kept as free as possible from sand, is important because, with the use of water only, a solvent action produces caving during drilling operations, whereas with a proper mud-laden fluid, the walls are preserved for a considerable depth.

In Assam the conditions appear to be similar to certain fields where good progress is now made by keeping the casing free. This is accomplished by cable tools, and with the latest design of under-reamers, allowing long strings of casing to be kept free, and constantly moving, and, what is most important, preserving valuable geological information with indications of gas and oil, which are lost or masked by the use of the Rotary process.

My personal impression is that with suitable percussion tools and good under-reamers, as now used in Burma and other parts of the world, with control of the casing in long lengths or strings, better results might be obtained in Assam. Much, of course, depends upon the engineers and labour employed, as the average cable driller of the early percussion school is not familiar with under-reaming and the handling of casing.

(2) By **Mr. Ashley Carter.**

Referring to fuel, Mr. Jack condemns firewood; he does not however state the type or details of boilers, in which the firewood was used, or the steam pressure. It would be interesting to know this and also what arrangements, if any, were adopted to deal with firewood, as several years' personal experience of this fuel, combined with coal, sometimes of poor quality, gave satisfactory results on locomotives in the East, with boiler pressure of 160 lbs. per square inch. It would appear there are difficulties in obtaining coal for the Assam Oil Co.'s fields, whereas there is a plentiful supply of firewood in the immediate vicinity of the wells, and the cost of the latter should be therefore much in its favour as compared with coal. Has any attempt been made to utilise gas or oil as fuel, and if so, with what results?

As regards combination rigs, there have been highly satisfactory results attained by their use, although it is possible their unsuitability on the Assam fields, mentioned by the author, may be due to the period of time occupied in effecting change from the one system to the other.

Has a trial been made of the hydraulic circulating system with mud-laden fluid? This method which is employed in conjunction with cable tools, is specially adapted for use in formations of varying hardness and stability, and has proved of special benefit in caving formations.

The expenditure for making the necessary additions to standard cable tool outfits is small, and although the rate of progress is slow as compared with the cable tool method, the hydraulic circulating system supplies an economical form of drilling, where conditions for its adoption are suitable.

(3) By **Mr. Hubert May.**

Far too little care and thought I consider has been given in the past to compiling accurate geological sections of wells. It has been customary in many oilfields to rely solely upon the report of the driller, whose knowledge of geology is obviously inadequate to enable him to correctly describe the various strata penetrated, particularly in an undeveloped field. From my own recent experience I realise the almost insuperable difficulty of correlating from inaccurate records the strata in different wells, the successful elucidation of which might and probably would effect in many instances an economy of large sums of money by reducing the number of dry holes. As it is almost invariably more economical to avoid trouble than to endeavour to overcome it, I suggest that it would profit many companies to employ on their staff a junior geologist whose duty would comprise a very close investigation of the drilling and the samples of strata obtained from the drilling débris, also the preparation of all geological sections. The information thus obtained would, I feel sure, be invaluable.

Another point which appears to me to be of much interest is Mr. Jack's statement that natives were in actual charge of wells, the skilled Canadian, American or other drillers acting as supervisors, presumably overlooking two, three or more wells each. This method has been proved to give every satisfaction in other countries, amongst which, I may mention, Peru, where natives have proved themselves very efficient under like supervision. I suggest that the natives of Burma if given an opportunity to show their skill would probably not prove themselves less capable, thereby checking the abuses prevalent under the existent regime.

Every credit is undoubtedly due to the staff, inexperienced in oilfield development outside Assam, in having successfully overcome a number of the problems which presented themselves during the early development of the property, but I question the advisability of adopting a similar procedure in most fields. I suggest that many of the difficulties encountered in almost all oilfields are very similar and that experienced men are far more capable of attacking a known problem with greater prospects of immediate success than a man with no experience, assuming other qualifications are equal.

Mr. Jack replies as follows upon the points raised :—

The mud-flush is used with the rotary drilling apparatus.

The supply of coal is ample, and this fuel is used as well as oil and gas. Wood is substituted only under conditions rendering it compulsory.

The Staff comprises two junior geologists, with functions much as suggested by Mr. May.

Twenty-Third General Meeting.

A meeting of the Institution of Petroleum Technologists was held at the house of the Royal Society of Arts, John Street, Adelphi, W.C. 2, on Tuesday evening, 15th May, 1917, Mr. Charles Greenway (President) occupying the Chair.

The Members of Council present were Messrs. Herbert Barringer, Andrew Campbell, E. H. Cunningham Craig, Arthur W. Eastlake, Dr. F. Mollwo Perkin and Sir Boverton Redwood, Bart.

Lady Redwood was among the visitors, and Vice-Admiral Sir Edmond Slade was present.

The President, in opening the meeting, said he had much pleasure in calling upon Mr. Bowrey to read a paper on "The Estimation of Toluene in Crude Petroleum." The subject was one of deep interest to all the members now that attention had been drawn to the fact that many qualities of petroleum contained substantial percentages of that very important essential of modern warfare, and he had no doubt that the paper and the discussion which would, he hoped, follow it, would be of advantage to all.

The following paper was then read, illustrated by lantern-slides of apparatus, some of which were also exhibited in action :—

The Estimation of Toluene in Crude Petroleum.

By S. E. Bowrey, B.Sc. (Lond.), *Associate Member.*

Owing to the shortage of toluene occasioned by the war it became necessary to investigate sources of supply previously neglected as unprofitable. Among the new raw materials proposed, petroleum has excited considerable interest, not only on account of the vast quantities now being handled, but also because the extraction of the aromatic hydrocarbons stated to be present in almost all varieties offers no obviously serious difficulties.

Before attempting to discuss the analytical problems presented by petroleum as a raw material, attention may be called to the important difference between natural and cracked spirit, and the influence exerted by that difference upon the method of analysis.

It is well known that by a properly-regulated cracking process considerable quantities of benzene and toluene can be generated from paraffin hydrocarbons, the product of such a process, as, for instance, that of Hall or Rittman, consisting of aromatic hydrocarbons, associated chiefly with highly unsaturated compounds. Examination of a cracked spirit for percentage of toluene therefore involves washing with sulphuric acid to remove these unsaturated substances, and fractional distillation of the remaining aromatics. It is a process which calls for considerable care and skill, but has no inherent difficulties.

Without digressing too far into the commercial aspects of the matter, it may be well to observe that cracking processes as at present practised are admittedly wasteful. This is particularly true of the benzene-toluene process, which, in turning out a relatively low percentage of the desired products, converts practically all the remainder of the raw material into gas, coke, and unsaturated substances of small value. On that account it is not surprising that proposals should be made to extract the naturally occurring benzene and toluene from the enormous quantities of petroleum now being produced, for, although the amounts present may be smaller than in the case of cracked spirit, the simple abstraction of benzene and toluene need not interfere in any way with economic utilisation of the remainder. Accordingly a demand has arisen for precise information as to the percentage of benzene and toluene in various crude oils and petroleum spirits. This demand confronts the analyst with a task quite distinct from the examination of cracked spirit, and gives rise to a number of small problems, which it is the object of the present paper to consider.

When a crude oil is under examination, the first operation is the elimination by distillation of all constituents boiling above, say, 150° C., and removal of unsaturated hydrocarbons from the distilled spirit by washing with sulphuric acid, alkali and water.

After the removal of the unsaturated compounds, the aromatic hydrocarbons are found associated with members of the paraffin and naphthene series, briefly referred to as paraffins, which cannot be removed by acid treatment. For the examination of this mixture, specific gravity is a test of considerable value. Indeed, if the specific gravities of aromatics and paraffins were known, that of the mixture would constitute a precise index of the percentages present. Since no appreciable change in volume occurs on mixing benzene, toluene or xylene with low-boiling paraffins, the relation between specific gravity and composition of a mixture is graphically represented by a straight line. The difference in density between the two classes of hydrocarbons is sufficient for fair experimental accuracy, but the difficulty of assigning an even approximately correct specific gravity to the paraffins in an unknown sample of spirit limits the application of the method to samples containing a large proportion of a known aromatic hydrocarbon, when variations in the paraffins will not greatly influence the result. It is possible to sulphonate the aromatic hydrocarbons, and note the percentage by difference, but unless the test is made with strict regard to temperature-conditions, and to the strength of the fuming acid employed, the results are unreliable. In any case, it has the uncertainty of an indirect method, and no subsequent examination of the aromatic hydrocarbons is possible, since quantitative recovery of the latter by hydrolysis of the sulphonic acids is impracticable.

Another method is that of nitration. The spirit is treated with nitrosulphuric acid in the usual manner, finishing at steam heat. The acid is withdrawn, diluted and extracted with ether. The residual spirit and the ethereal extract are then washed with 5 % caustic soda, and with water, distilled, and the residues united and weighed. By again nitrating the distilled spirit a further yield amounting to about 5 % of the total nitrocompound is obtained. This has the penetrating odour of nitroparaffins, but the results are not seriously vitiated by the presence of these substances, since they are mainly removed by the soda treatment. It is not possible to calculate the percentage of aromatic hydrocarbons directly from the weight of nitrocompound, since the composition of the latter is unknown. The difficulty can, however, be overcome by estimating the nitrogen by Kjeldahl's (modified)

method, calculating to NO_3, deducting the weight of NO_3 and adding an equivalent of H, or if the quantity be small, the arbitrary factor can be employed of 1 gramme nitrocompound = 0·700 cc. aromatic hydrocarbon. This test, whilst affording indications generally correct to within 1 % of the total amount of aromatic hydrocarbons, gives no information as to the content of toluene. Nor can much be gained by testing the nitrocompound. Attempts to regenerate the hydrocarbons from it by the usual text-book methods failed of quantitative success as conspicuously as in the case of sulphonic acids.

A somewhat obvious alternative is to split the original petroleum distillate, by careful redistillation, into separate fractions for benzene, toluene and xylene. Nitration or sulphonation of each fraction would then afford all the information required. This method has been stated on good authority to be the best available, and has been therefore tried very carefully, not only in the laboratory, but also with a 10-ton plant in a Trinidad refinery. The limitations of this process are due to the pronounced tendency of aromatic hydrocarbons to form mixtures of constant boiling-point with members of the paraffin series. Such mixtures may be formed with one or all of the many paraffin compounds present, and it will be readily understood, that when the paraffins predominate (as they do very largely in most light petroleum distillates), it is almost impossible to secure all the toluene within a fraction which shall contain no benzene or xylene. It would not be advisable to assert that these mixtures of constant boiling-point cannot be broken up by systematic redistillation, given unlimited time and patience, but it is a fact that several experiments carried to the third refractionation with Young & Thomas, evaporator, rod and disc and other stillheads led only to rough approximations.

Attention was therefore redirected to the possibility of initial removal of paraffins, and the utility of selective solvents, such as alcohol, acetone, aniline and liquid sulphur dioxide, was investigated. Each of these substances, when shaken with a mixture of paraffin and aromatic hydrocarbons, dissolves a greater proportion of the latter, but only in the case of liquid sulphur dioxide was the selective action found sufficiently pronounced to be developed into an analytical process. This may be owing to the fact that SO_2 was tried at a low temperature, which has been shown to favour selective action, but in any case it has the advantage over the other substances that its low boiling-point and acid character offer special facilities for subsequent removal.

The use of liquid SO_2 in the treatment of petroleum is of course

chiefly associated with Edeleanu's process for refining lamp oil, and it was on the lines recommended for laboratory work by this chemist that experiments were first made, that is to say, the distillate was agitated with successive charges of liquid SO_2 in a vessel cooled to $-12°$ C. by means of ice and salt. It was found, however, that the conditions prescribed for the extraction of aromatic hydrocarbons from lamp oil are not equally satisfactory when applied to lighter distillates. For example, at $-12°$ C. the lamp oil fraction from a Trinidad crude treated three times with half its volume of liquid SO_2 yielded extracts as follows:—

TABLE I.

Extraction.	Extract.	Sp. gr. of extract.	Sulphur in extract.
I	15·0 %	0·896	0·87 %
II	9·0 %	0·887	1·00 %
III	4·4 %	0·876	0·93 %

Sp. gr. of original distillate = 0·832 %
Sulphur content of ditto = 0·476 %

By sulphonation, the extract was shown to contain only about 10 % of paraffins—a highly satisfactory degree of separation. On the other hand, a light distillate (up to 150° C.) from the same crude yielded extracts containing about equal parts of aromatics and paraffins.

By working at temperatures considerably lower than $-12°$ C., it was found possible to improve the results up to a point at which a satisfactory correction could be applied by means of sp. gr. determination. Table II gives a series of results on an artificial mixture and serves to show the influence of temperature. The constituents of this and all other artificial mixtures employed in checking results were purified, the aromatics by fractionation until distillation could be completed within 1° C. of the theoretical boiling-point, and the paraffins by washing Pratt's Spirit with fuming sulphuric acid until free from aromatics, neutralising and redistilling. The writer has to thank Dr. Thole for preparing certain of the test mixtures.

TABLE II.

Treatment with liquid SO_2 of a mixture containing (by volume):

Paraffins (sp. gr. 0·717 at 15·5° C.) ..	85 %
Benzene	5 %
Toluene	5 %
Xylene	5 %

Expt.	Qnty. SO_2.	Working temp.	Qnty. of extract.	Sp. gr. of extract.	Aromatics in extract deduced from sp. gr.
	Approx.				
1.	10%	0°C.	8·8%	0·757	26·3%
2.	10%	−12°C.	3·7%	0·797	52·6%
3.	10%	−25°C.	3·0%	0·817	65·7%
4.	10%	−35°C.	4·0%	0·837	79·0%
5.	50%	−35°C.	10·5%	0·838	79·6%
6.	100%	−35°C.	11·0%	0·845	84·3%
7.	50%	−12°C.	25·0%	0·803	56·7%

These results demonstrate the necessity for working at a temperature below that conveniently obtainable by means of freezing mixtures, and might seem to involve the use of special apparatus, were it not for the fact that SO_2 is of itself a most efficient refrigerating agent, which, under the vacuum of an ordinary water pump quickly falls to − 35° C.

The apparatus employed is illustrated in Fig. 20.

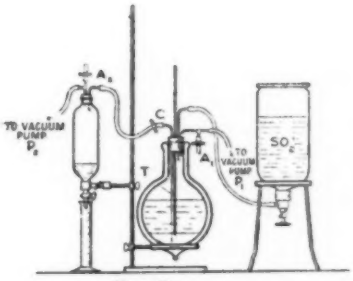


Fig. 20.

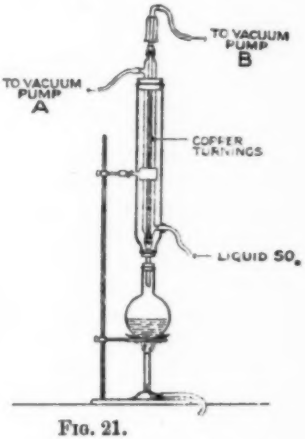


Fig. 21.

It consists of a Dewar flask of about one litre capacity, fitted with a thermometer and airtight connections to an inverted SO_2 syphon, a vacuum pump P_1, and a separating funnel. The tube T, communicating with the separating funnel, is drawn out to a capillary, and reaches to the bottom of the flask. The separating funnel

is in turn supplied with a connection to a second pump P_2, and both pump connections are provided with side-tubes A_1 and A_2 for the admission of air. By opening these side-tubes the vacuum can be broken, but any SO_2 vapour evolved will continue to be drawn into the pumps, where it dissolves in the water. Even when the pumps discharge into a sink, only a slight smell of SO_2 is perceptible. 500 cc. of the sample having been placed in the flask, pump P_1 is started with side-tube open, and SO_2 slowly admitted. In a few moments the temperature will have dropped to the liquefying point $-8°$ C., at atmospheric pressure, and liquid SO_2, having saturated the sample, will begin to collect beneath it. By now closing the side-tube A_1, vacuum is applied, and the SO_2 is thrown into ebullition, whereby the contents of the flask are well mixed, and the temperature is reduced to any desired point down to $-35°$ C. Air is then re-admitted, and the screw-clip C, closing the connection to the separating funnel, is opened. The action of pump P_2 draws the lower layer of SO_2, containing aromatic hydrocarbons in solution, into the separating funnel, and C is then closed. Owing to the very low temperature attained, no previous cooling of the separating funnel is necessary, and evaporation of the SO_2 proceeds under the vacuum of pump P_2 at the rate of about 100 cc. per hour. This slow rate is due to the insulating effect of the frost which collects on the funnel, and should not be increased by warming, since it is desirable to distil off the SO_2 very slowly, and so hinder volatilisation of hydrocarbons dissolved in it. It should also be remarked that the capillary tube provides an efficient means of separating liquid SO_2 from the supernatant paraffins, so long as both liquids are free from suspended matter, such as particles of ice. Syphons of SO_2 occasionally contain traces of water, which gives rise to much trouble by freezing out, and causing obstructions. It is therefore advisable to examine the SO_2 before use by spraying a little on a glass plate, when any moisture present will appear as a white film of frost, and the syphon can be rejected.

If it is desired to dry a consignment of SO_2, distillation or agitation under pressure over a desiccating agent will be found preferable to any attempt to filter or desiccate the liquid at low temperatures. Considerable assistance in noting the separation between supernatant spirit and SO_2 is obtained by colouring the latter, e.g. with a trace of aniline green.

A sufficient number of extractions having been carried out, the funnel is watched for the rise in temperature, which indicates completion of the removal of SO_2. As soon as this occurs, a 10 %

solution of caustic soda is admitted to absorb SO_2 vapours, drawn off again, and the hydrocarbons run out and measured.

Table III gives the results of ten successive extractions of an artificial mixture of 15 % aromatics and 85 % paraffins. The specific gravities of the extracts were determined separately, and used to deduce the percentage of paraffins and aromatics in each, a procedure which is justifiable even when a natural product is being examined, for the proportions of the three aromatic hydrocarbons can be ascertained as described below, thus establishing their combined specific gravity with accuracy, whilst a moderate degree of uncertainty as to the specific gravity of the paraffins cannot appreciably vitiate the result, owing to the small proportion present.

TABLE III.

Repeated extractions with liquid SO_2 at − 35° C. of a mixture containing (by volume) :—

Paraffins	85 %
Benzene	5 %
Toluene	5 %
Xylene	5 %

Extraction.	Volume of SO_2.	Volume of extract.	Sp. gr. of extract at 15·5° C.	Paraffins* in extract.	Aromatics* in extract.
1st	10%	4·7%	0·844	0·77%	3·93%
2nd	10%	4·3%	0·837	0·90%	3·40%
3rd	10%	2·7%	0·825	0·78%	1·92%
4th	10%	1·7%	0·841	0·31%	1·39%
5th	10%	1·3%	0·844	0·21%	1·09%
6th	10%	1·3%	0·830	0·33%	0·97%
7th	10%	0·7%	0·835	0·16%	0·54%
8th	10%	0·7%	0·829	0·18%	0·52%
9th	10%	0·3%	0·837	0·06%	0·24%
10th	10%	0·3%	0·797	0·14%	0·16%
Total extracted ..		18·0%	—	3·84%	14·16%
Residue (insoluble in SO_2)		53·3%	Aromatics in residue (by nitration test)		0·27%
Total evaporation loss (by difference)		28·7%	Aromatics lost (by difference)		0·57%
		100·0			15·00%

* Deduced from specific gravity.

It will be seen that the total extract and the residue left in the flask total 28·7 % short of 100. This deficiency is, of course, due to volatilisation of pentane and other light hydrocarbons with the SO_2, and so long as it is confined to paraffins is quite immaterial.

The loss of aromatics is shown in column 6 to be 0·57 %. A number of experiments were made with a view to eliminating this source of error, which, it was found, arises chiefly in evaporating off SO_2 from the extract. First, alcohol scrubbers were inserted in the connection to the pumps. They recovered only traces of hydrocarbons. Secondly, alcohol was mixed with the SO_2 and aromatics without effect. Thirdly, the whole of the SO_2 was absorbed in caustic soda: theoretically this method is perfect, but in practice the large bulk of solution required leads to mechanical losses greater than the previous evaporation losses. Fourthly, benzene was mixed with five times its volume of liquid SO_2, and the SO_2 evaporated under vacuum as described already. The loss of benzene was 9 %. Toluene similarly treated lost only 2 %. This method was therefore retained for ordinary work, and evaporation-losses were regarded as consisting of four parts benzene and one part toluene.

It was felt, however, that something should be done to ensure absolute freedom from error of this kind when desired, especially when the percentage of benzene was of importance. To this end a modified apparatus of the form shown in Figs. 21 and 22 was constructed.

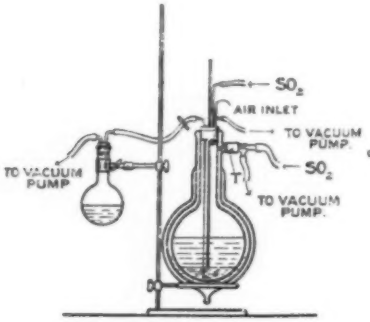


FIG. 22.

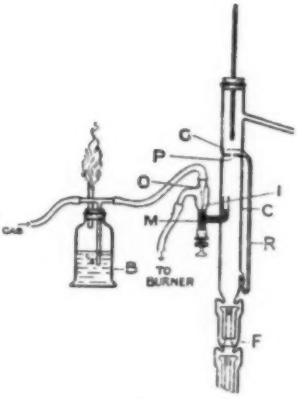


FIG. 23.

The Dewar flask was replaced by a three-walled vacuum flask, of which the side-tube T, communicating with the inner jacket, had been opened, and connected to an extra SO_2 syphon and vacuum pump, so that the contents of the flask could be cooled by evaporation of SO_2 in the jacket. Instead of evaporating

the extracts in a separating funnel, they were drawn into a flask, and freed from SO_2 by means of the special distilling apparatus illustrated in Fig. 21.

The dephlegmator consists of a glass tube loosely packed with copper turnings, and fitted with a narrow Liebig condenser jacket containing liquid SO_2, the temperature of which can be varied at will by means of pump A. An outer glass jacket serves to prevent deposition of frost. A gas burner is needed to keep the distillation going, and the removal of 100 cc. of SO_2 takes fully an hour. This apparatus enables the total loss by evaporation to be kept well below 1 % of the spirit present. Unfortunately, it is less easily constructed than the apparatus first described, takes longer to operate, and requires much more SO_2. All the results quoted were obtained with the simpler apparatus, which requires about one 3-lb. syphon of SO_2 for two determinations, and with which an estimation of toluene can be completed in one day.

It is unnecessary to continue washing the sample with SO_2 until the extraction of aromatics is complete, although as a check upon the nitration test such procedure may be adopted. The primary object of the extraction is to secure a specimen of aromatics sufficiently free from paraffins for further examination. Thus the question arises, whether the first few washings extract an average specimen of aromatics, or whether there is a selective action tending to bring out, say, the benzene first. To test this point a mixture containing :—

Paraffins	85·00 %
Benzene	4·86 %
Toluene	5·58 %
Xylene	4·56 %

was given seven successive washings with SO_2. The extracts from the 1st and from the 4th, 5th, 6th and 7th united were then examined by a method described below, with the results shown in Table IV.

TABLE IV.

Composition of aromatic portion of :—

	Original sample.	1st extract.	4th, 5th, 6th, 7th extracts united.
Benzene	32·4 %	34·0 %	28·5 %
Toluene	37·2 %	37·7 %	37·4 %
Xylene	30·4 %	28·3 %	34·1 %
	100·0	100·0	100·0

The figures show a distinct tendency for benzene to dissolve out in preference to xylene—a result which might be anticipated on theoretical grounds.

For ordinary purposes, however, this selective action may be ignored, provided always that the bulk of the aromatics are extracted. In the above instance, the first extract contained 26 % of the total aromatics present, and its examination gives results which, on account of selective action, led in the analysis of the sample to an error of 0·24 % in the benzene, 0·07 % in the toluene and 0·32 % in the xylene. Seeing that the error diminishes the more one extracts, it is obviously unnecessary to spend time and material in washing out the last traces, provided that no conditions exist which would vitiate the method (nitration or other) used in estimating them.

A specimen of the aromatics having been isolated, it remains to determine its content of benzene, toluene and xylene. It is legitimately assumed that the original spirit distils entirely below 150° C., and has been initially freed from unsaturated hydrocarbons by washing with sulphuric acid. Naphthenes are insoluble in SO_2, and are therefore left with the paraffins.

The quantity of extract available will necessarily be small, say, 50–100 cc., and cannot be dealt with by one of the rapid methods for estimating toluene, such as that of James or Coleman, owing to the presence of some 20 % of paraffins. The best plan is to fractionate very slowly, cutting at 75°, 85°, 105°, 115° and 130° C. A small "evaporator" column is the best form of stillhead, but a tube filled with copper turnings gives excellent results, and it should be noted that regular, very slow distillation is much more important than the type of stillhead. Six drops per minute is a fair maximum speed. To distil at so low a rate requires considerable care on the part of the operator, and prolongs the running of a 50 cc. charge for about three hours, in addition to augmenting evaporation losses, unless special attention is given to joints. Disturbing influences frequently ignored assume exaggerated importance; for instance, slight draughts and fluctuations of gas pressure, due to the use of other taps on the same supply, are enough to spoil the test unless countered immediately. In spite of these difficulties it is indisputable that, where only a small specimen is available, it is better to spend time and trouble on a single test than to make any attempt to refractionate. Probably this statement is also true of many laboratory distillations of larger quantities, only the operator's impatience or lack of care rendering repeated redistillation necessary.

Being faced with the necessity of obtaining accurate fractionation by once distilling a small quantity of liquid, and appreciating the advantages of exactly regulating the speed of the test, the writer made certain attempts to produce a self-acting regulator, analogous to the Reichert temperature-regulator, which would at once save trouble, and replace erratic hand-work by mechanical precision. A number of electrical devices having been tried and discarded as too cumbersome, an apparatus was evolved in which the vapour passes through a narrow orifice in the stillhead, and the slight increase of pressure thus occasioned within the distilling flask is made to operate a mercury cut-off, acting upon the gas supply. The design is shown in Fig. 23 (p. 294). On leaving the fractionating column F, the vapour enters a chamber C, from which it can only escape by a pinhole P, communicating with the thermometer chamber and the condenser. To distribute the vapour evenly around the thermometer, a disc of gauze is placed at G, whilst provision for return of degraded distillate from the thermometer chamber is made by means of the reflux tube R, capable of holding sufficient head of liquid to descend against the pressure in C, which having been adjusted according to the rate of distillation desired, is kept constant by the action of the mercury cut-off M. Should the pressure fall, mercury recedes from the gas inlet I, and the increased flow of gas to the burner generates more vapour until the pressure exceeds the predetermined amount, driving the mercury to close the gas inlet, and leave only a by-pass flame (due to the outlet O) beneath the flask, after which the action is repeated. The result is an oscillation of the gas supply between wide limits, but always adapted to the maintenance of a predetermined pressure in the apparatus, and consequently to a steady flow of vapour through the pinhole P to the condenser. The mercury in the regulator is adjusted by the usual piston device.

Since the action of the regulator depends on the pressure in the gas main, an escape bottle B is provided to keep that pressure steady. It contains spindle oil, and when the gas pressure rises above a certain amount, allows the excess to escape.

Table V gives the results of applying this method of examination to two known mixtures of pure benzene, toluene and xylene, using a small 5-section "evaporator" stillhead, and working at the rate of six drops per minute.

In judging the efficiency of a process of fractional distillation, the relative size of the intermediate fractions may be taken as a criterion. In the given cases they represent a smaller percentage of the total than when a sample twice as large is distilled with an

TABLE V.

MIXTURE No. 1.—CHARGE = 50 cc.

Fraction.	Amount cc.	Corrected for loss.	Intermediate fractions divided equally.	Per cent.	Percentage actually present.
Below 80° C.	Nil	Nil	Nil		
80-- 85° C.	14·0	14·8	15·85	(benzene) 31·7	33·3
85—105° C.	2·0	2·1			
105—115° C.	13·5	13·7	16·95	(toluene) 33·9	33·3
115—130° C.	4·4	4·4			
Residue	15·0	15·0	17·2	(xylene) 34·4	33·3
	48·9				
	Loss = 1·1				

MIXTURE No. 2.—CHARGE = 49·75 cc.

Fraction.	Amount cc.	Corrected for loss.	Intermediate fractions divided equally.	Per cent.	Percentage actually present.
Below 80° C.	Nil	Nil	Nil		
80-- 85° C.	4·5	5·22	6·07	(benzene) 12·2	11·35
85—105° C.	1·7	1·70			
105—115° C.	20·45	20·63	23·33	(toluene) 46·9	46·30
115—131° C.	3·7	3·70			
Residue	18·5	18·50	20·35	(xylene) 40·9	42·35
	48·85	49·75			
	Loss = 0·90				

Corrections for evaporation-losses during distillation are made upon the basis of ½ benzene and ½ toluene.

8-section "evaporator" stillhead at the usual rate of one drop per second (*see* Young's comparison of "evaporator" stillheads, "Fractional distillation," p. 169. 1903). In calculating the results, they are divided equally between adjacent main fractions. It should not be assumed that the results given indicate the maximum efficiency obtainable by means of a self-regulating stillhead. On the contrary, if sufficient time can be allowed, and the apparatus made secure against leakage, the rate of working can be much further reduced, with corresponding gain in accuracy.

The specimen of aromatic hydrocarbons extracted by SO_2 having been tested in this way, it remains to determine the specific gravity of each fraction by means of a small Sprengel tube, and to evaluate therefrom the content of benzene, toluene or xylene, as the case may be. This step is necessary, because no method has yet been found of completely eliminating paraffins. Fortunately the specific-gravity test affords a means of rapidly and accurately

making allowance for the small quantities of paraffins usually remaining. For the purpose of these calculations the specific gravity at $\frac{15{\cdot}5}{15{\cdot}5}$° C. of benzene is taken as 0·884, toluene 0·870, and the isomeric xylenes 0·865. That of the paraffins is deduced from the range of distillation by simply determining the specific gravity of similar fractions from pure paraffin spirit. The writer is indebted to Dr. Spielmann for pointing out that when benzene is distilled with small quantities of paraffins, the paraffins found in the distillate at 80° C. are not generally of the normal specific gravity (about 0·690), but much heavier. This objection was confirmed by isolating the paraffins in the several fractions derived from the SO_2 extract of a natural petroleum spirit, when the figures were found to be:

Fraction.	Sp. gr. of paraffins isolated.
75—85° C.	0·715
85—105° C.	0·724
105—115° C.	0·727
115—130° C.	0·747

Unfortunately there is still some uncertainty attaching to these figures, owing to the very minute quantities of material available, and the rapidity with which evaporation takes place during the six or eight washes with fuming sulphuric acid which are needed to extract the aromatics. It will be seen that only the benzene would be affected by adopting them, and that only to the extent of some 7 % of the amount present. The matter has therefore been left open pending further work.

The amounts of benzene, toluene and xylene found in the distilled extract having been extended to the whole, and additions *pro rata* having been made on account of nitration, the results are complete.

The following typical analyses may serve to show the degree of accuracy obtainable, the operator in each case having been unaware of the composition of the sample:—

I.—Analysis of artificial mixture containing (by volume):—

Paraffins	77·5 %
Benzene	7·2 %
Toluene	8·9 %
Xylene	6·4 %
	100·0

300 cc. washed with 50 cc. liquid SO_2 at − 35° C. six times

Fractionation of 70 cc. of extracted aromatics and calculation of results.

Temperature range.	Distillate. (cc.)	Corrected for loss during distillation. (cc.)	Sp. gr. at 15·5°C. of distillate.	Sp. gr. at 15·5°C. of aromatics.*	Sp. gr. at 15·5°C. of paraffins.*	Volume of aromatics deduced from sp. gr. (cc.)	Distribution according to boiling-point. Benzene. (cc.)	Toluene. (cc.)	Xylene. (cc.)
Below 75°C.	2·0	2·2	0·748	0·884	0·680	0·7	0·7	—	—
75–85	16·7	18·3	0·841	0·884	0·690	14·2	14·2	—	—
85–105	5·0	5·3	0·815	0·877	0·700	3·4	1·7	1·7	—
105–115	20·9	21·2	0·843	0·870	0·720	17·4	—	17·4	—
115–135	8·1	8·1	0·840	0·867	0·750	6·1	—	3·1	3·0
Residue	14·9	14·9	0·852	0·865	0·760	13·0	—	—	13·0
Totals	67·6	70·0	—	—	—	—	16·6	22·2	16·0

* Found by testing pure specimens distilling in the same range.

(after which no more could be extracted) yielded 81·6 cc. of extract, sp. gr. 0·838 at 15·5° C. Paraffins remaining amounted to 114 cc. after washing with alkali, leaving 104·4 cc. to be attributed to evaporation-loss. This high proportion is due to the presence of an abnormal amount of pentane. The following table gives the result of subsequent examination of the extract to determine the proportions of benzene, toluene and xylene therein.

These proportions, extended to the whole extract, give—Benzene 19·4 cc., toluene 26·0 cc., xylene 18·7 cc., and since extraction with SO_3 was carried to completion, there is no addition to be made on account of unextracted aromatics.

Percentage results :—

	Analysis.	Actual.	Error.
Benzene	6·5 %	7·2 %	− 0·7 %
Toluene	8·7 %	8·9 %	− 0·2 %
Xylene	6·2 %	6·4 %	− 0·2 %

In connection with these specimen results, it may be pointed out that the analysis consists of two parts: first an extraction process and a fractional distillation based on well-known physical laws, and secondly a number of corrections, largely dependent on the writer's observations. The latter, being limited in number, it may be objected that the accuracy of the proposed methods of correction is not well established. To show that such an objection need not discredit the method as a whole, the total influence of the corrections in the given example has been calculated in the form of difference between result with and without correction.

Correction.	Influence on results.	
For loss during distillation (empirical) ..		+ 0·9 %
For presence of paraffins in extract (by sp. gr. method)	Benzene	− 2·4 %
	Toluene	− 2·1 %
	Xylene	− 1·1 %
For imperfect fractionation (by distribution of intermediate fractions)	Benzene-Toluene	1·4 %
	Toluene-Xylene	2·7 %

A very considerable error in the application of the corrections would be needed to vitiate the results seriously.

II.—Analysis of artificial mixture containing (by volume) :—

Benzene	5·74 %
Toluene	7·28 %
Xylene	3·22 %
Paraffins	83·76 %

Fraction.	Distillate. (cc.)	Corrected for loss.	Sp. gr. at 15·5° C.	Sp. gr. of aromatics deduced from b.-pt.	Sp. gr. of paraffins deduced from b.-pt.	Volume of aromatics deduced from sp. gr. (cc.)	Distribution according to boiling-point. Benzene. (cc.)	Toluene. (cc.)	Xylene. (cc.)
0–75°C.	2·3	2·7	0·753	0·884	0·680	0·97	0·97	—	—
75–85	13·8	16·1	0·833	0·884	0·690	11·85	11·85	—	—
85–105	5·5	5·7	0·782	0·877	0·700	2·62	1·31	1·31	—
105–115	15·7	16·3	0·854	0·870	0·720	14·56	—	14·56	—
115–130	3·0	3·0	0·858	0·867	0·750	2·77	—	1·39	1·38
Residue	6·2	6·2	0·869	0·865	0·760	6·20	—	—	6·20
Totals	46·5	50·0	—	—	—	—	14·13	17·26	7·58
Extended to whole extract 78·2 cc.							20·70	25·27	11·87
7·1 cc. unextracted aromatics distributed *pro rata*							2·54	3·10	1·46
Total amount in sample							23·24	28·37	13·33
Per cent.							5·81	7·09	3·33
Actual							5·74	7·28	3·22
Error							+0·07	−0·19	+0·11

400 cc. washed with 40 cc. liquid SO_2 at $-35°$ C. seven times yielded 73·2 cc. extract and 294 cc. paraffin residue, which on nitration was found still to contain 7·1 cc. of aromatic hydrocarbons.

The results of fractional distillation of 50 cc. of the extract are set out on the opposite page.

Determination of Toluene in Crude Oil from Trinidad Central Oilfields.

1,800 cc. crude oil were distilled at 10 drops per minute up to 150° C., yielding 745 cc. of spirit (41·4 %), sp. gr. 0·733, which on shaking with 90 % sulphuric acid lost approximately 0·2 %.

600 cc. treated with SO_2 yielded 58·4 cc. extract, sp. gr. 0·844, and 480 cc. residue containing 15·2 cc. aromatics.

Fractional distillation of 49·5 cc. of the extract :—

Fraction ° C.	Distillate (cc.)	Corrected for loss (cc.)	Sp. gr. at 15·5° C.	Volume of aromatics deduced from sp. gr. (cc.)	Distribution according to boiling-point. Benzene (cc.)	Toluene (cc.)	Xylene (cc.)
0–75	1·05	1·25	0·755	0·47	0·47	—	—
75–85	4·8	5·0	0·817	3·34	3·34	—	—
85–105	3·65	3·75	0·801	2·16	1·08	1·08	—
105–115	15·7	15·9	0·848	13·68	—	13·68	—
115–130	3·0	3·0	0·843	2·50	—	1·25	1·25
Residue	20·6	20·6	0·862	20·10	—	—	20·10
Totals ..	48·8	49·5	—	—	4·89	16·01	21·35
Extended to whole extract 58·4 cc.					5·77	18·89	25·20
15·2 cc. unextracted aromatics distributed *pro rata*					1·75	5·76	7·69
					7·52	24·65	32·89
Percentage on spirit					1·25%	4·11%	5·48%
,, ,, crude oil					0·52 %	1·70%	2·27%

The writer deeply regrets his inability to adduce more experimental evidence in support of the empirical methods used, confirmatory work of any considerable extent being impossible in a commercial laboratory already working at full pressure on other matters.

It has already been pointed out, however, that the empirical features of the method affect only minor corrections, bearing to a very limited degree on the main results.

The subject having been approached in the first instance on behalf of Trinidad Central Oilfields, Ltd., with a view to ascertaining whether their crude oil contained enough toluene to be worth extracting, the results quoted for crude petroleum deal with that Company's spirit.

The work of investigating the sulphur dioxide method for estimation of aromatics in petroleum spirit has encouraged speculations as to the possible utility of liquid SO_2 for other work. Whilst the treatment of lamp oil by Edeleanu's process is well understood, the published accounts display a certain reticence concerning application of the same process to heavier oils. A few tentative experiments in this direction show that there may be, if not a prospect of commercial profit, at least an interesting field for research. Spindle and machine oils yield an extract darker and more viscous than the original oil, which to prevent freezing must be largely diluted with petrol before treatment and freed therefrom afterwards. The sulphur-content of the oil is slightly increased by the treatment with SO_2. It might therefore be well to replace that solvent by alcohol at a low temperature, but apart from the possibility of inferior selective action, alcohol has not the advantage of high specific gravity and resulting ability to separate rapidly from the oil.

It has been suggested that the SO_2 process would be useful in refining shale oils and cracked spirit. The difficulty here is that the unsaturated hydrocarbons which constitute the bulk of these products are soluble in SO_2. The writer experimented with a specimen of cracked spirit containing 80 % unsaturated hydrocarbons, 16 % benzene, toluene and xylene, and 4 % paraffins, and found it completely soluble in liquid SO_2 at $-35°$ C. To what extent a chemical reaction took place was not investigated, but there were no outward signs of reaction, and the spirit appeared to be unchanged after evaporating off the SO_2.

Since it is well known that most sulphur compounds found in petroleum are soluble in SO_2, and can be separated by it from pure paraffins, it would appear that the process might be useful in desulphurising shale-oil, were it not for the solubility of the unsaturated hydrocarbons. The SO_2 process is, however, only a particular application of the general method of selective solution, which has been much neglected in relation to mineral oil, and may on further investigation afford a means of effecting separations now impracticable. The solvent action, for instance, of liquid carbon dioxide, nitrous oxide and ammonia, does not appear to have been studied in this connection. The method of selective solution has the great advantage that it need not disturb the most sensitive chemical structures—structures which would undergo complete alteration if submitted to distillation, or brought into combination with reagents in any of the commoner methods of analysis. The subject in its wider aspects may be worth notice.

The writer's thanks are tendered to Messrs. A. Duckham & Co. for their kindness in affording facilities for laboratory work, to Mr. Alex. Duckham, Dr. Dunstan, and Prof. Brame for much helpful criticism, and to Miss E. M. Thomas for able assistance with the practical work.

DISCUSSION.

The President, to open the discussion, read the following letter from **Mr. A. Duckham** :—

I had looked forward with much pleasure to being present at the reading of the paper by Mr. Bowrey, for this gentleman has been working for my Companies for several years, and this investigation into the estimation of toluene in crude petroleum really, I think, arose from the criticism which I made to him of the few and very inaccurate methods which were in vogue in laboratories.

I greatly regret that there seems no chance of my being present, owing to my detention by work at the Ministry of Munitions.

I think this paper will be welcome, not only because it affords evidence of most painstaking work and of a proper use of the imagination, which use is one of the most valuable assets to a research chemist, but also because I believe it is the first purely chemical paper that has been read before the Institution of Petroleum Technologists.

I know that you will agree with me that the chemistry of petroleum has, in the past, been much neglected; and one has to admit that the greater part of the research work into the chemistry of petroleum and many of the laboratory methods owe their origin to foreigners. British work should be encouraged, and therefore I shall be glad if the Council of the Institution would accept an offer from me of an annual prize for the best paper that may be read in any one year; the form of the prize would be, of course, for discussion with the Council.

Another point I welcome in the reading of this paper by Mr. Bowrey is that he is one of our younger members—and, indeed, only an Associate-member; and I hope that other young members will be encouraged by his example to offer papers, for, after all, it is from the younger members that we have a right to expect new ideas.

The President thought the Council would not only agree with Mr. Duckham's proposals, but would even go a step further, and approve of the suggestion that a prize should be given each year

for the best paper on each branch of petroleum technology, namely, geology, chemistry and refining. The question as to what form the prize should take would of course have to be considered by the Council, but in his opinion the most suitable form, and the one that he thought would be most acceptable to the members, would be a medal.

He was sure all the members had listened with great interest to the paper which had just been read. The subject was, he was afraid, too abstruse a one for him to express any views upon it which would be of scientific value; but one point upon which he, as a business man, would like some enlightenment beyond what had been given by the author was what proportion of the theoretical aromatic hydrocarbon contents of any given quality of petroleum, ascertained according to the empirical method of examination explained by the author, might reasonably be estimated as being commercially obtainable. He would be glad if in the course of the discussion the author, or some of the other members, would give the benefit of their experience or of their studies in that respect. It was, of course, dependent largely upon the nature of the process of fractionation or separation employed, but any estimate to be of value must naturally be based upon a process which could be carried out remuneratively on a commercial scale. In the case of the Trinidad crude to which the author had referred, it had been shown that the theoretical aromatic hydrocarbon contents were, he thought, equal to about 11 % on the spirit and 4½ % on the crude. Those results were, however, deduced from the specific gravity, which he presumed might not be conclusive. What the business man would like to know was, firstly, could that empirical deduction be relied upon as a guide to the actual contents of aromatic hydrocarbons, or might it not be vitiated by the presence of certain sulphur or other compounds of corresponding specific gravities; and, secondly, what proportion of those contents could be reasonably estimated as commercially extractable? If those points could be elucidated by the author they would, he was sure, add much to the value of the paper from a commercial point of view.

Prof. J. S. S. Brame thought the members would agree that the author had set an example to the younger members which it would be very difficult for them to follow, as he had set such a high standard in the paper he had read. Nevertheless, he was sure the Council would look forward in the future to other papers presented by the younger members in view of the excellent one that had been read on the present occasion.

The author had very kindly afforded him opportunities of witnessing in operation his process of extraction, and one thing with which he had been particularly struck was the remarkable skill and ingenuity and the pretty devices which had been adopted in order to bring about the extraction in a suitable manner with a liquid agent which was not by any means the most easy to handle. He considered the author had made an enormous advance in the technique of the Edeleanu process, which was first proposed, he believed, for the refining of petroleum, but it was also adopted by Edeleanu for the estimation of aromatic hydrocarbons: Mr. Andrew Campbell, in a paper read before the Institution about 12 months ago, dealt with that process from the commercial point of view. He regretted that the author had not been able to include in his paper a rather more full description of Edeleanu's original analytical process, because had he done so the members would have realised better what enormous improvements the author had made in it. Until recent events forced upon the country the importance of increasing its supply of aromatic hydrocarbons, the amount present in most petroleum distillates had been practically a matter of interest only to, he might say, the scientific chemist; but, like many other things, the dire necessity of the war had naturally changed that position, and, the production of aromatic hydrocarbons from petroleum having now become a commercial proposition and a branch of industry, the chemist must be prepared with methods of examination of the raw material and of the control of the process. It was fortunate the author had brought the subject before the Institution that evening, because that branch of the industry was now in its early days, and it was very desirable that there should be a good discussion on the subject.

The author had briefly summarised the methods available for the estimation of the aromatic hydrocarbons. Broadly they might be classified as the physical, depending very largely on the specific gravity; the chemical, depending upon conversion into nitro-compounds and sulphonic-acid compounds; and, thirdly, a method which might be either physical or chemical, and which might be described as physico-chemical—the solution method, followed afterwards by the chemical method. There were one or two points in connection with specific gravity to which he desired to refer. A good deal hinged on specific gravity in all methods, and therefore it was very important to see clearly the bearing of results deduced from specific gravity purely and simply. The author stated that the method was applicable where there were reasonably high proportions of aromatic hydrocarbons. Broadly speaking that was

quite true, but he thought the author's statement was erroneous that there was no appreciable change of volume on mixing aromatic hydrocarbons with paraffin hydrocarbons. If there was a change of volume, it to a certain extent vitiated deductions made from the specific gravity of the mixture. Whenever hydrocarbons were referred to, the members were reminded of the classical researches of Sydney Young and his colleagues; and in papers published in 1898 Jackson and Young showed that when benzene and normal hexane were mixed together considerable expansion took place. Another point was the fact that paraffins had an abnormal gravity when they had been extracted by fractionation from a complex mixture containing aromatic hydrocarbons, and the author gave a table shewing that the specific gravity, especially at the boiling point of benzene, was materially higher than would be expected for a paraffin hydrocarbon boiling over that same range. He noticed that the author took in his calculations the true values of the specific gravity. Would it not be better if the values actually determined from the mixtures were taken, and would that appreciably affect the result? Another point to which reference was made was the very abnormal specific gravity of the hydrocarbons, mainly aromatic hydrocarbons, extracted from the lamp oil fraction of Trinidad petroleum, the specific gravity obtained for the first fraction being ·896, and for the second fraction ·887.

It was a very remarkable thing that the Trinidad oil should have yielded extracts of such an abnormally high specific gravity, a higher specific gravity than any liquid aromatic hydrocarbon. It might be that some concentration or condensation took place, and he would like to know from the author, with his great experience of Trinidad petroleum, whether there was any other abnormality about it which might account for that result. Whilst referring to specific gravities he desired to urge the great necessity that existed for some recognised standard temperatures at which specific gravities were quoted. The system at present used was a most haphazard one, and something in the way of standardisation was required in that respect.

He desired to refer, in the next place, to the question of fractional distillation, because a good deal hung upon it. In any of the processes to which the author had referred, the question of fractionation had to come in sooner or later. He desired to point out that the original composition of the petroleum probably made a very great difference as to the fraction in which the specific aromatic hydrocarbon appeared. Benzene, for example, as the author pointed out, in general tended to form mixtures of constant

boiling-point. Young found that a mixture of benzene, 60 %, with methyl alcohol, 40%, had a constant boiling-point of 58° C.; and in a paper which Young published in 1898, dealing with American petroleum, he pointed out that nearly the whole of the benzene was found in the fraction boiling between 65° and 66° C. Young found hardly any benzene in the fraction boiling over 71° C., and none in the fraction boiling below 60° C., and he pointed out that benzene and hexane behaved as liquids which were only partially miscible. Then, as proving his point that the original character or the source of the petroleum might influence the fraction in which the aromatics particularly appeared, Markovnikov, working with Russian petroleum, found the benzene occurred in a different fraction from that which Young had found for the American petroleum. Markovnikov found that he had some benzene between 60° and 70°, but that the bulk of the benzene occurred in between the fraction 70° and 80°.

Toluene was probably uppermost in the minds of the members that evening, and Young had found that toluene came over at temperatures far below its ordinary boiling-point.

Turning to the sulphur-dioxide process of extraction, it appeared from Edeleanu's original paper that what he did was to extract with the sulphur dioxide, to measure the change in volume which he obtained by the sulphur dioxide extraction, and then, from the specific gravity of the extract and the volume of the extracted and unextracted material, calculate the actual percentage of compounds. Of course the author's examination by fractionation of the aromatic hydrocarbons which were obtained was an undoubted advance, because it gave at any rate an approximate individual result for the aromatic hydrocarbons, whereas they were all measured together in the Edeleanu process. It appeared to him that in the author's process the greatest error would probably arise from the assumption as to specific gravities to which he had already referred.

In the second place, there was the empirical correction introduced through the loss by evaporation of light spirit. In one case it amounted to 28·7 %, but the author had practically overcome that in the new form of apparatus he had described, but he had not been able to place before the members the actual results obtained. It certainly appeared distinctly preferable to have correction eliminated if it was at all possible to do so.

In conclusion, he desired to pay his tribute of admiration to the system of regulating distillation in the piece of apparatus exhibited on the table. It was one of the neatest pieces of apparatus for a specific purpose that he had seen, and he thought the author was heartily to be congratulated on its design. As a very amateur

glass blower, he also desired particularly to congratulate the author on the remarkable success he had achieved in its construction.

Dr. F. M. Perkin said he was sure all the members desired heartily to congratulate the author upon the extremely interesting results he had obtained from his process. Before reading the paper, which he had done very carefully, he had thought the sulphur dioxide process to be one which could not very well be carried out upon a laboratory scale, because from the original paper the conclusion was arrived at that high pressure, and so on, were necessary in order to carry it out. But, with the aid of the very ingenious apparatus which the author had described, and the Dewar flasks, it now seemed to be a process which could be carried out by the ordinary chemist in his laboratory, and extremely useful results would no doubt be obtained.

The question of the unsaturation and saturation of the hydrocarbons in oils which at present came before the notice of the chemist was one of extreme importance, and by means of the author's process it was possible to estimate, with a very considerable degree of accuracy, the relative amounts of between saturated and unsaturated hydrocarbons. In 1908 he carried out a long series of investigations in reference to the separation of aromatic hydrocarbons from mineral oils. In those investigations he did not use sulphur dioxide, because the process was not known in those days; and he doubted, in any case, whether he could have obtained the apparatus or possessed the necessary ingenuity to carry out the work. He used dimethyl sulphate, which entirely dissolved aromatic hydrocarbons. To a certain extent it dissolved hydrocarbons of the methane and naphthene series, although in much smaller proportion. The hydrocarbons of the unsaturated series were also more or less soluble in dimethyl sulphate. At the time referred to, his attitude was not so much to get rid of the benzene and toluene, or to find out the amount of benzene and toluene in the hydrocarbons, but to test the charge put forward, particularly in Germany, that lubricating oils were very often adulterated with sharp oil or green oil, i.e. the heavier coal-tar oils; and Valenta had stated that dimethyl sulphate would dissolve the higher hydrocarbons of the aromatic series, and leave the saturated hydrocarbons. After carrying out a long series of experiments he came to the conclusion, in conjunction with one of his assistants, Mr. Harrison, that the use of dimethyl sulphate could not be recommended as a quantitative method, because the results were irregular. Neither, however, was the process of sulphur dioxide absolutely quantitative; but with sulphur dioxide the bulk of the aromatic hydrocarbons could be got rid of, with only

a small quantity of the paraffin hydrocarbons; and by further treatment it was possible to eliminate practically the whole of the aromatic hydrocarbons as distinct from the paraffin hydrocarbons. He was not at all certain that dimethyl sulphate might not be employed in a similar manner; and it possessed the advantage, if it was effective, of not needing extremely low temperatures. Dewar flasks and similar apparatus were rather expensive, and required very careful manipulation. On the other hand, taking $1\frac{1}{2}$ volumes of dimethyl sulphate compared with 1 volume of the hydrocarbon being dealt with, it was possible to abstract the bulk of the aromatic constituents, with only a small quantity of the paraffin hydrocarbons. It would then be found that the products separated into two layers, the upper containing the ordinary paraffins and the lower the dimethyl sulphate *plus* the aromatic hydrocarbons. A volume reading then gave an approximate measure of the separation, although he admitted it was only approximate. The lower layer could afterwards be decomposed with caustic soda or caustic potash solution, and from that would be obtained the aromatic hydrocarbons *plus* a small percentage of the paraffin hydrocarbons. From that, by nitration or other means, it should be possible to get a very close approximation to the amount of aromatic hydrocarbons present. He intended at the first opportunity to carry out a research to see whether dimethyl sulphate might not be another—he did not say a better—means of arriving at similar conclusions to those which the author had obtained. The only drawback to the use of dimethyl sulphate compared with sulphur dioxide was its poisonous nature, necessitating extreme care in working with it. It was quite easily made, but it was a very nasty substance to work with. If it got upon a man's hands or into his system it might effectively terminate his career of usefulness. Sulphate dioxide was unpleasant, but its action upon the system went off very rapidly. With ordinary care dimethyl sulphate could be very much more readily used, as he had already mentioned, at ordinary atmospheric temperatures than sulphur dioxide. Those were matters with which the members were naturally concerned; they were present with the endeavour to find out the best methods in that particular case of analysis.

The author had been treating an oil of great interest, one which contained aromatics, and which also contained low fractions in the petrol series in an extraordinary degree; and all the members were very thankful indeed, not only to the author but to Mr. Duckham and those associated with him, for the work that had been carried out. It was difficult to imagine a more ingenious apparatus than

that which had been described. The fact that the work had been carried out in a commercial laboratory, in which a large amount of other work had of necessity to be done, showed that commercial men were beginning to recognise the value of chemical research.

Mr. H. V. Mitchell enquired whether the author had had the opportunity of examining Rumanian crude oil in the manner described in the paper. Some 14 years ago he attempted to estimate the percentage of benzene and hydrocarbons generally in Rumanian oils; he isolated a fraction from the oil by distillation, which he nitrated, and he thought he had a true nitro-aromatic to deal with. On reduction it formed an amino-compound, which acetylated, and gave a crystalline acetyl-derivative resembling acetanilide: but whilst it was somewhat analogous to the aromatic series, it was not truly aromatic in character; it did not for instance form a diazonium salt. He did not know whether those remarks applied to any other crude oil, and he would like to know whether any similar results had been obtained in the crudes which the author had examined.

Dr. A. E. Dunstan said it would be generally agreed that the author had brought forward a valuable addition to the methods in vogue for the estimation of aromatic hydrocarbons in the presence of paraffins, cycloparaffins and unsaturated compounds. It was possibly worth while briefly to extend his criticism of the other methods, and to realise in what particulars they failed to justify themselves, or in what way they might possibly be made use of at any rate for approximate determinations. The nitration method was perhaps the most attractive, seeing that one could recover a weighable solid derivative of the original aromatic compound present in the mixture. In point of fact, however, such a procedure was highly deceptive, for complete nitration on the laboratory scale was most difficult to achieve (Professor Cohen gave 80 % as the laboratory yield of mono-nitro-benzene; whilst in working up pure toluene to T.N.T., it was difficult to attain a higher percentage than 80 % of the theoretical amount, according to Professor Hoffmann, of the United States Bureau of Mines), and there were also secondary actions taking place, which produced catenary nitro-compounds of uncertain nature and properties, and possibly, further, a variety of oxidation-products. Francis and Young, *Journ. Chem. Soc.*, vol. lxxiii, pp. 928-932 (1898), had shown that strong nitric acid did not attack normal paraffin, but reacted with polymethylenes, and readily with iso-paraffins. For example, iso-heptane, iso-octane, and di-iso-butane gave mono- and tri-nitro-

derivatives at the temperature of the boiling water bath. For those reasons an arbitrary co-efficient had to be introduced.

A method, which depended on sulphonation, had been in use in his own laboratory for some time, and had given most satisfactory results. Briefly, it consisted in absorbing the unsaturated hydrocarbons with concentrated sulphuric acid by agitation in a stoppered burette, followed by the successive action of small amounts of slightly fuming acid, containing 3 % free SO_3, all the operations being carried out at the temperature of tap water. The second series of absorptions removed the bodies of the aromatic class, leaving a residue of saturated catenary or cyclic hydrocarbons, which was washed, dried and used for the determination of specific gravity. It might conceivably be argued that it was well known that the higher members of the paraffin series were capable of sulphonation. That was quite true, but in the case under consideration, up to the boiling-point of the xylenes, there were no higher members of the series present, and, again, Engler (Das Erdöl, vol. i) gave an account of experimental work which showed that even a concentration of 10 % free SO_3 had little or no action on paraffins at moderate temperatures. Furthermore, he had found that cyclohexane was quite incapable of being sulphonated under the conditions which he had specified. The specific-gravity method should always be used as an adjunct of the absorption process, for it would be readily seen that, if one knew the density of the olefine-free spirit and also of the aromatic-free paraffinoid hydrocarbons, it was an easy matter to determine the percentage of either the aromatic or the saturated component. It might be said that the results agreed quite well amongst themselves, and the method had now been tested by several well-known petroleum chemists. Both the sulphonation method and the Edeleanu method depended ultimately on fractionation, but, whilst Mr. Bowrey carried out his distillation last, he, personally, on the other hand cut his fraction first.

The author's results of a single fractionation at the speed of 6 drops a minute were truly excellent, and he quite agreed with the author on the question of rate of flow when one possessed so capital a pressure regulator as that described in the paper. But Dr. Thole and he (the speaker) had found that results could be obtained which would bear comparison with the author's, using the rate of 60 drops a minute, and distilling over a Raschig column, which was home-made, and consisted merely of pieces of $\frac{1}{4}$ in. copper tube. The following experiment would illustrate that point. With a mixture consisting of 100 cc. pure benzol and

100 cc. pure toluol, a distillation rate of 1 drop per second, and a length of column of 1 metre with a diameter of 1·5 cm., the following result was obtained:—

80°– 85° C.	...	...	...	93 cc.
85°–108° C.	...	...	...	7 cc.
Residue	...	...	...	100 cc.

During the period 85°–108° the mercury in the thermometer could be seen rising steadily, and by reducing the velocity of distillation better fractionation could no doubt have been obtained. As that was probably the first recorded description of a laboratory-scale Raschig apparatus, Dr. Thole and himself trusted that other petroleum chemists might find it of value. Their procedure was simply to distil the spirit through either a Raschig or Young-

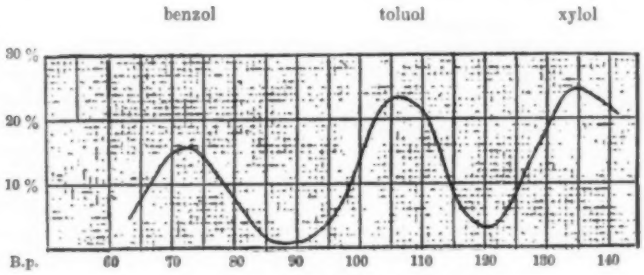


FIG. 24.—Distribution of Hydrocarbons in Benzene.

Thomas evaporator 5-section column. The cuts could be made at any convenient stages. They preferred to combine the purely aromatic analysis with systematic fractionation, so as to obtain some information about the chief components that made up the spirit. Each fraction was examined for specific gravity loss to C.O.V. and to F.O.V. The values thus obtained were plotted against distilling ranges, and it was then possible to read off from the curves the amounts of benzol, toluol, etc., which were contained in the benzine (fig. 24). Fig. 25 showed some of the results of a six-fold run on a certain benzene, which clearly demonstrated the presence of pentane, hexane and heptane, the latter in great abundance. Those hydrocarbons might readily be isolated after an acid wash, and their presence proved by molecular weight determination and ultimate analysis. The fractionation-curve, fig. 26, might also be of interest.

The author pointed out that the recovery of the specific aromatic hydrocarbon from the sulphonates was impracticable as a

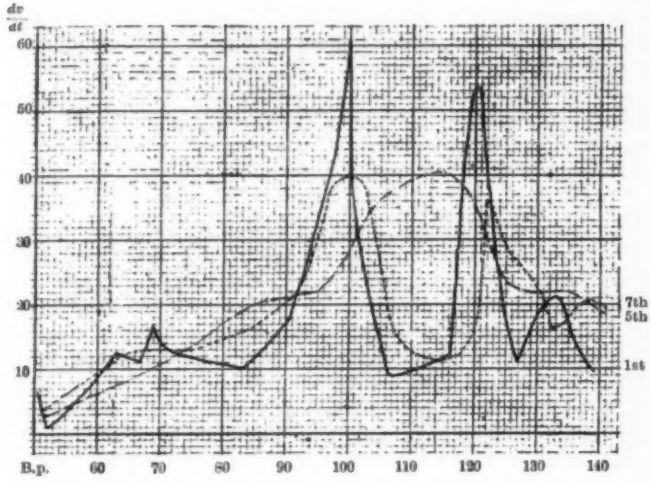


FIG. 25.—Benzene: 1st, 5th and 7th fractionations.

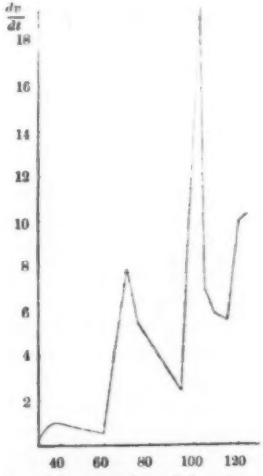


FIG. 26.—Continued fractionation of benzene.

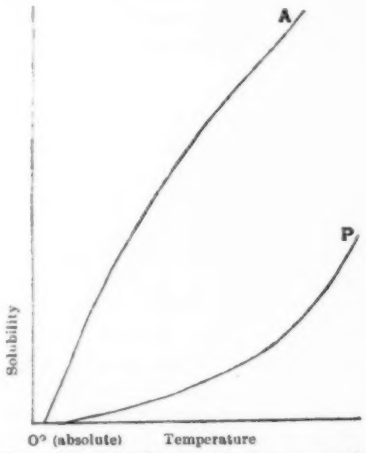


FIG. 27.—Solubility in SO_2: A, aromatic hydrocarbons; P, paraffins.

quantitative method. That might certainly be correct, but it could be done qualitatively, and Dr. Thole had, in point of fact, isolated chemically pure benzol and toluol from a natural petroleum. The raw material was concentrated as to its aromatic content by means of sulphur dioxide, and the extract was fractionated.

First fractionation of extract in Raschig column :—

B.P.	35° C.	Sp. gr.	
Up to 75° C.	43 cc. ...	0·722.	
75° „ 85° ...	40 cc. ...	0·777	benzene concentrated.
85° „ 95° ...	25 cc. ...	0·729.	
95° „ 105° ...	56 cc. ...	0·761.	
105° „ 115° ...	147 cc. ...	0·826	toluene concentrated.
115° „ 125° ...	26 cc. ...	0·760.	
125° „ 135° ...	45 cc. ...	0·792.	
135° „ 145° ...	172 cc. ...	0·839	xylenes concentrated.

The fractions near the benzol (60°–90°) and toluol (100°–117°) and xylol (130°–140°) ranges were sulphonated in the usual way, and the acid extracts were diluted with an equal bulk of water and separated from further paraffins, and submitted to hydrolysis in sealed tubes, to 280° C. in the case of the benzene-sulphonic acid, and to 250° C. in the two other cases. The regenerated hydrocarbons were separated, washed with caustic soda to remove all traces of acid, dried and distilled, when the physical and chemical characteristics proved beyond doubt that the substances which were isolated were pure benzene, toluene and the xylenes :—

	B.P.	Sp. gr. (15·5° C.)
Benzene	81° C.	0·884
Toluene	110° C.	0·871
o, *m* & *p*-xylene ...	137°—141° C. ...	0·873

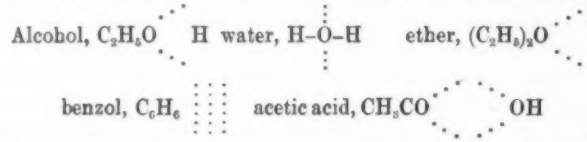
He would like to make a few comments on the author's observations concerning the Edeleanu process. It appeared from the author's work that sulphur dioxide was a far better specific solvent for aromatic hydrocarbons, and much less for paraffins at lower temperatures than Edeleanu recommended. Apparently the solubility of the paraffinoid compounds rose with the temperature, as indeed was their common behaviour, and the solubility curves diverged with the lowering of temperature (fig. 27).

The effect of the mutual concentration of the three component classes was more complicated. When one contemplated the somewhat analogous case of an ether extraction where the components were (1) ether, (2) water, and (3) solute, one could easily realise that the ether was preferentially a better solvent for the solute than was water. But in the case under consideration, sulphur dioxide

and paraffin were competing for the aromatic hydrocarbons, and the mutual solubilities of (*a*) aromatic—SO_2 and (*b*) paraffin—aromatic were unknown, since each liquid pair was mutually miscible in all proportions. It was impossible to say offhand at any temperature, pressure and concentration, which was the superior solvent. Experiment, however, showed that at relatively low temperatures the sulphur dioxide dissolved, it was true, both paraffins and aromatics, but the latter were the more soluble. The question furthermore was complicated by the fact that, once aromatics had entered into solution, the simple state of affairs he had just predicated no longer existed, for paraffins were themselves soluble in the mixture of sulphur dioxide and aromatics. It was evident, therefore, that no simple theoretical treatment on the lines of an ether extraction was likely to yield a satisfactory solution; but if the two solvents were merely regarded as competing for the aromatic hydrocarbons, it was obvious that one must employ the largest amount of sulphur dioxide that the limitations of the experiment would allow. That point was borne out by the author's experiment detailed on page 293. The first 10 % of SO_2 extracted aromatics in the ratio of 3·93 aromatics to 0·77 paraffins; and the last 10 % in that of 0·16 aromatics to 0·14 paraffins. It would be seen that in the last case the extract contained approximately equal volumes of paraffins and aromatics. A similar effect was seen in the author's second table, pp. 290, 291, wherein

10 %	SO_2 at	— 35° C.	dissolved	4 %	of extract of	sp. gr.	·837
50 %	,,	,,	,,	10·5 %	,,	,,	·838
100 %	,,	,,	,,	11·0 %	,,	,,	·845

To what was the selective action of sulphide dioxide to be ascribed? That question led to a survey of the very foundations of physical chemistry. Why were certain liquids solvents? Alcohol, water, ether, benzol, acetic acid, and so-forth were excellent solvents, and a little consideration showed that they were all unsaturated:—



All those bodies possessed residual affinity, denoted by the dotted lines, and to a very marked extent so did sulphur dioxide, $\vdots SO_2$

During the Edeleanu process sulphur dioxide united with other unsaturated compounds, forming loose complexes or molecular

aggregates :—benzene and sulphur dioxide, $C_6H_6...SO_2$, mercaptan, and sulphur dioxide, $CH_3SH...SO_2$.

It was no answer to assert that such complexes had not been isolated. Chemical literature contained a vast number of instances of such loose alliances, often only made apparent by the abnormalities of physical properties. In some cases, however, those liaisons had come to light directly, as, for instance, Pickering's isolation of the hydrates of sulphuric acid and of caustic soda. He agreed with the author that the extension of such principles as selective absorptions in the processes of petroleum refining might be brought about, if researches of the kind under discussion were undertaken.

In answer to the President's question, as to whether it was commercially practicable to translate the analysis into fact, he was inclined to think that, although every trace of the aromatic hydrocarbons could commercially be abstracted, it would not be financially profitable to do so. It would be better, in his opinion, to compromise, to take out three-quarters and leave the last quarter, because of the extra expense involved in extracting it.

Dr. F. B. Thole wished to make two suggestions which might possibly improve this excellent and accurate method of estimating aromatic hydrocarbons.

Mr. Bowrey estimated the non-aromatic content of his benzene and toluene fractions by specific gravity determinations, assuming that the non-aromatic hydrocarbons are paraffins of specific gravity 0·690 and 0·720 respectively. In many oils, however, the non-aromatic hydrocarbons were partly naphthenic, therefore possessing specific gravities considerably higher than those of the paraffins of similar boiling-point. It would therefore appear more satisfactory to remove the aromatic hydrocarbons from the fractions in question by sulphonation, and to determine by direct measurement the specific gravity of the non-aromatic residue.

The assumption that the intermediate fractions consist in equal part of the two aromatic hydrocarbons present was probably correct in the case of the toluene-xylene, but hardly so in the benzene-toluene fraction. Though an error here has but little influence, owing to the small volume of these fractions, the distillation of a mixture of benzene and toluene under the conditions usually employed in this method of analysis would afford an experimental, instead of an arbitrary, ratio for the division of the intermediate fraction.

Mr. S. E. Bowrey, in reply, said the percentage of spirit contained in the crude oil from Trinidad Central Oilfields was much

higher than that in oil from other parts of the island. In fact, the spirit and kerosene together constituted about 70 % of the crude, the residue being a clear red oil containing only traces of asphalt.

His results were based upon specific gravities so far as the correction was concerned. The extent of that correction had been studied, and shown to be something in the neighbourhood of 2 %. As to the possibility of the correction being vitiated by the presence of sulphur-compounds, in the first place he was not particularly troubled by that consideration in the case of Trinidad oil, because the percentage of sulphur in the light spirit was too low for such possibility, and secondly as a more general proposition, he thought it likely that the sulphur-compounds, at all events those of high gravity, would be largely removed by the preliminary treatment with sulphuric acid. He quite agreed with Prof. Brame's suggestion that the best course to adopt was to take actually determined specific gravities for paraffins associated with the aromatics in the final fractionation, but he had not sufficient faith in the figures obtained so far to do so. The quantities secured at the finish by sulphonating the extract were so exceedingly minute, and they evaporated so readily that during the repeated treatments with fuming acid and transference to a Sprengel tube their gravity might have changed. He therefore preferred to rely for the present upon the figures obtained by fractionating pure paraffin spirit. With regard to the specific gravities of kerosene extracts, he had a copy of Edeleanu's paper read before the American Institute of Mining Engineers, giving figures for a great variety of kerosenes from which the specific gravities of the SO_2 extracts could be indirectly ascertained. He found that the specific gravity of Edeleanu's extract was approximately the same in some instances as that of the Trinidad extract. It varied a great deal; in some cases it was over 0·9, but in others it was lower. The results mentioned by Prof. Brame for the fractionation of Russian and other petroleums confirmed the difficulties of carrying that process far enough to separate benzene and toluene. He was sorry that he had not been able to try Dr. Perkin's suggested method of using dimethyl sulphate. He believed dimethyl sulphate was unobtainable commercially at the present time. He had also not had the opportunity of examining Rumanian oil by the SO_2 process, so that he was unable to corroborate the results mentioned by Mr. Mitchell. The very interesting fractionation curves which Dr. Dunstan had shown must have represented a considerable amount of highly skilled work. Dr. Dunstan had carried out six fractionations, which meant that if

the first distillate was divided into six fractions, the second step involved a separate distillation of each, the third step called for another six tests, and so on up to a total of thirty-one distillations. The results obtained in regard to the nature of the paraffins were unobtainable in any other way, but for the purpose of estimating the aromatics he thought it was much more simple and straightforward, as well as equally accurate, to extract them by a selective solvent, and then fractionate them in a single test.

Dr. Dunstan had raised a point as to the imperfections of the nitration method, a yield of only 80 % being quoted. That yield was from the treatment of benzene or toluene alone. It was, he thought, an explanation of the higher yields obtained experimentally in the course of the work he had occasion to do, that the paraffins diluted the benzene and toluene, preventing too drastic an action, tending to reduce oxidation and also to prevent evaporation losses by covering the material.

He had not found it necessary to introduce an arbitrary co-efficient in order to allow for the presence of nitroparaffins, but only to allow for the presence of di- and tri-nitro-aromatics. This co-efficient was arbitrary only when the estimation of nitrogen was omitted; it could be ascertained precisely in any particular case by carrying out that estimation, and so finding how far nitration had gone. At the same time he readily agreed that the nitration method was fraught with some uncertainty in dealing with substances so imperfectly understood as the constituents of petroleum.

He had experienced a good deal of difficulty in working the sulphonation process. On one occasion a sample of spirit was given six washes with fuming acid of 4 % free SO_3, and it was found that even then all the aromatics had not been extracted.

In working these and other indirect methods, one was constantly troubled by the fact that a substance which simulated benzene or toluene, whether by forming a nitro-compound or by dissolving in fuming sulphuric acid, could not forthwith be assumed identical with those hydrocarbons. These difficulties, he thought, emphasised the advantage of the SO_2 process in yielding benzene and toluene quantitatively in a state such that tests of identity could be readily applied.

With regard to the excellent results obtained by Dr. Dunstan with the modified Raschig column, he would like to urge that such results should not be compared directly with his own. The quantity distilled was four times as large, and had only two ingredients instead of three. The apparatus shown would have to be reduced in size before it could be used for a small charge, and his

experience with similar apparatus consisting of tubes filled with copper turnings, went to show that a reduction in size meant decreased efficiency, unless accompanied by a reduced rate of working. Hence the self-regulating device. That device was intended not to supersede, but to supplement the column. He thanked Dr. Thole for the two very sound suggestions he had made. It was possible to judge to some extent whether naphthenes were present in sufficient amount to vitiate the specific gravity correction by observing the specific gravity of the non-aromatic portion of the sample remaining after extraction with SO_2. This could be done either directly or by calculation from the specific gravity of the extract, and that of the original spirit. More exact results could be secured by distilling the non-aromatic portion, and taking the specific gravity of each fraction. He had a distrust, perhaps unreasonable, of the sulphonation method, which led him to avoid it as much as possible. Dr. Thole had mentioned that the fraction intermediate between benzene and toluene did not consist of equal parts of those substances. It was certainly desirable to split the intermediate fractions accurately, and he would be glad to have any data Dr. Thole could supply, but hitherto his attention had been chiefly directed to making the intermediate fractions negligibly small.

The President, in moving that a hearty vote of thanks be accorded to the author for his very able and interesting paper, said he felt sure that great benefit would accrue from the discussion. Personally he felt he had gained considerably in knowledge on a question which was of very great importance at the present time, although the business side of it, in which he was more particularly interested, had not received much attention in the discussion. The resolution of thanks was carried by acclamation, and the session terminated.

The **Author** desires to add the following remarks:—

During the discussion it became evident that the sp. gr. correction necessitated by the presence of paraffins in the SO_2 extract would not be accepted as perfectly reliable.

Whatever view of the correction may be taken, it is obvious that the failure to separate benzene and toluene in a pure state detracts from the value of the analytical process, and would be a serious obstacle to its industrial application. For instance, simple extraction with SO_2 would not afford a solution of the difficulty experienced in eliminating paraffins from benzole obtained by the ill-fated Rittman cracking process.

A method of purifying aromatics has since been evolved, whereby the analysis is practically reduced to quantitative extraction of pure benzene, toluene and xylene.

It consists in adding to the SO_2 extract five times its volume of kerosene (previously washed with liquid SO_2 if necessary), and again extracting with SO_2.

The paraffinoid portion of the mixture undergoing the second extraction thus consists mainly of kerosene, and although the second extract may still contain paraffins, these, with the exception of a negligible proportion, boil above 150° C., and are eliminated in course of fractionation.

The writer is informed that the proposal to hinder extraction of light paraffins by adding kerosene has been put forward already, but being unable to trace its publication, deems it advisable to record it here. Reference to previous promulgation (if any) will be welcome. *Suum cuique tribuito.*

INDEX.

Acidity of fuel-oil, 197.
Air as atomising agent, 205, 209, 252.
—— excess in furnaces, 213, 217, 221, 252.
—— forced draught, 218.
—— preheating, 211, 221.
Alaska, recent formation of oil, 32.
Alcohol blend with cracked spirit, 115.
Alkyl sulphides, 232, 244.
Analyses of Fuel-oil, 197, 199.
—— Norfolk oilshale, 22.
——, —— shale oil, 24.
Anfilogoff, N. A., on sulphur in fuel-oil, 219, 243, 248.
Anticlines of S.E. England, 163.
Aromatic hydrocarbons in crude petroleum, 287.
—— in shale-oil, 29, 33.
—— pyrogenesis of, 36.
Assam, Petroleum Industry, 263.
Atomisers for fuel-oil, 201, 207.
Atomising agents, 205, 209, 252.

Barringer, H., on oil-fuel combustion, 218.
Benzene, 38, 287.
Bibliography of Pyrogenesis of Hydrocarbons, 91.
Blackler, M. B., on pyrogenesis of hydrocarbons, 113.
—— on desulphurisation of oils, 249.
Booth, W. H., on oil-fuel combustion, 223.
Boulton, Prof. W. S., Address at British Association criticised, 1.
Bowrey, S. E. The Estimation of Toluene in Crude Petroleum, 287, 319, 321.
Brame, Prof. J. S. S., Liquid Fuel and its Combustion, 194, 225.
—— on toluene estimation, 306.
Brickwork in furnaces, 213, 225.
Burton cracking plant, 61.
Bush, H. J., on submerged oil burners, 224.
Butterfield, J. C., obituary notice, no. 11, p. viii.
Butterfield, W. J. A., on sulphur in shale-oil, 33.
—— on pyrogenesis of hydrocarbons, 118.
—— on aerial *v.* ground railways in oil fields, 281.

Cadman, Prof. J., on British oil-shales, 27.
—— on geological mapping, 144.
—— on liquid fuel, 216.
Cadman, Prof. J., on the Presidential Address, 261.
—— on adjustment of drilling system to local conditions, 280.
Calder, W., Mexican Oilfields, 35.
Caledonian axes, 163.
Calorific values of fuel oils, 196, 199.
Carboniferous petroleum, 159, 178, 181, 183.
Carter, A., on drilling and fuel in Assam oilfields, 284.
Catalysts in pyrogenesis of hydrocarbons, 46, 81, 118.
Chambers, Capt. D. McDonald, obituary notice, no. 11, p. viii.
Charnian axes, 161, 171, 193.
Classification, use and abuse of, 191.
Coal, pulverised, as fuel, 223, 225, 226.
Coal-tar oils, 198.
Cooper-Key, Major A. Fire-extinction, no. 11, p. ix.
Co-ordination of Energies, 121, 259.
Correlation by petrography, 148, 150.
Cracked oils, constituents of, 87.
Cracking, discovery of, 38.
Cracking, see Pyrogenesis.
Craig, E. H. C., on oil-shale, 29.
—— on pyrogenesis of hydrocarbons, 120.
—— on geological mapping, 149.
—— on petroleum in England, 186.
—— on chemical criteria as to origin of petroleum, 248.
—— on difference between petroleum and shale-oil, 249.
—— on mineral discovery by animals, 279.
Cumberland, oil occurrence, 154.

Dalton, W. H. Science and Petroleum, 1.
—— Co-ordination of Energies, 121.
—— estimation of distances, 145.
—— Kelham boring, 189.
—— petroleum in England, 190.
—— Good servant, bad master, 191.
—— Mineral Rights, 255.
—— on salt licks (pungs) in Assam, 279.
Derbyshire oil occurrences, 8, 154, 156, 178.
Desulphurisation of shale-oil, 25, 27, 29, 33, 233, 242, 245, 304.
Devon, oil occurrence, 154.
Dienes, 116, 120.
Diolefines in cracked spirit, 89, 114, 120.
Dorsetshire oil-shale, 7.
Duckham, A., on toluene estimation, 305.

DUCKHAM, A., proposes prizes for papers, 305.
DUNSTAN, A. E., on shale-oils, 28.
—— The Pyrogenesis of Hydrocarbons, 36, 120.
—— on toluene estimation, 312.

Eastern Palæozoic Plateau, 173
Edeleanu process, 237, 247
Electricity-production by oil-fuel, 215, 223.
English oil-shales, 3.
—— petroleum, 152.
—— tectonics, 159.
Erythrene, 83.
Essex oil shale, 11.

Fire-extinction, no. 11, p. ix.
Flash-point of fuel-oil, 196.
Foamite fire extinction, no. 11, p. x.
FORBES-LESLIE, W. Norfolk Oil-shales, 3, 33.
—— Petroleum in England, 152, 189.
FORD, T., on the Kelham boring, 187.
Forest, geological mapping in, 137, 147, 150.
Free oil in oil-shales, 18, 23, 28, 30, 180, 189.
Fuel-oil, acidity of, 197.
——, calorific values, 196.
——, flash-point, 196.
—— official specifications, 196, 219.
—— viscosity of, 196.
—— water in, 196, 220.
Furnaces for oil burning, 211, 225.

Gas, periodicity of outbursts, 35.
Geological Mapping, 123.
Geology shown by surface-contour, 140, 150.
Gloucestershire oil occurrence, 155.
GREENWAY, C. Presidential Address, 257.
—— on the Assam oilfields, 276, 282.
—— on toluene estimation, 306.
"Gum" in "cracked" spirit, 89, 114, 116, 120.

HENDERSON, Dr. J. A. L., on oil-shale, 31.
—— on petroleum in England, 188.
—— on oil-fired locomotives, 220.
HOLIDAY, F. A., obituary notice, no. 9, p. ix.
Hydrocarbons, Pyrogenesis of, 36.
——, aromatic, in shale-oil, 29, 33.
—— —— estimation in crude oil, 287.

ILLING, V. C., on geological mapping, 145.
Imperial College of Science and Technology—Students in War-work, no. 11, p. x.
Industrial heating with oil fuel, 222.
Isochores, 147, 192.
Isopachytes, 147.

JACK, H. S. M. The Development of the Petroleum Industry in Assam, 263, 281, 286.
JAMES, S. L., on Geological Mapping, 123.

Kelham, Notts, oil discovery, 154, 156, 178, 181, 183, 185, 187, 189.
Kent oilshale, 11.
Kerogen, modes of occurrence, 20.
Kimmeridge Clay, 3, 179.

Lancashire oil-occurrences, 154, 178.
LEWER, R. R., obituary notice, no. 9, p. viii.
Lincolnshire oil-occurrences, 155, 157, 179.
Liquid Fuel, 5, 194.
Literature of petroleum, 1.
Locomotives, oil-fuel in, 216, 220.
LOMAX, E. L. The Pyrogenesis of Hydrocarbons, 36.
—— on sulphur in petroleum, 245.
London Palæozoic platform, 172.
LUCAS, A. D., on pyrogenesis of hydrocarbons, 117.
Lucas oil-cracking plant, 50.

MACDOUGALL, A., on Government aid in oilfield development, 280.
MANFIELD, W. H., on oil-shale, 31.
—— on free oil in Norfolk, 189.
Mapping, geological, 123.
Mathematics and Nature's "vagaries" 192.
MAY, H., on geologically inaccurate well logs, 285.
Mercaptans, 239, 244, 247.
Mesozoic rocks, thickness, 182.
Metallurgy, oil-fuel in, 222, 224.
Methane production, 120.
Mexican Oilfields, 35.
MITCHELL, H. V., on Rumanian oils, 312.
Mud-flush drilling, 284, 286.

Naphthalene reduces viscosity of fuel oil, 208.
New Brunswick oil-shale, 32.
Nitration of hydrocarbons, 288.
Nobel oil-combustion system, 199.
Norfolk oil-occurrences, 157, 180.
—— Oil-shales, 3.
North Sea floor contour, 161.
Notts oil occurrences, 154, 156, 178, 181, 183, 185, 187, 189.

Ockenden, M. A., on drilling in Assam oilfields, 283.
Oil-combustion, 194.
—— systems, 199.
Oil in recent shell-beds, 32.
Oil-occurrences, Cumberland, 154.
—— Derbyshire, 8, 154, 156, 178.
—— Devonshire, 154.
—— Gloucestershire, 155.
—— Lancashire, 154.
—— Lincolnshire, 155, 157, 179.
—— Norfolk, 157, 180.
—— Nottinghamshire, 154, 156, 178, 181, 183, 185.
—— Shropshire, 155, 185.
—— Somersetshire, 155, 184.
—— Staffordshire, 155.
—— Wales, 154, 178, 185.
—— Yorkshire, 154, 180.
Oil-reserves, 4.
Oil-shales, British, 3, 256.
—— History of utilisation, 8.
—— free oil in, 18, 23, 28, 30, 180, 189.

Palæontology, use and abuse of, 191.
Paraffin wax, Assam, 273, 280.
Patents: Cracking Oils, 94.
Pennine axis, 161.
Perkin, F. M., on pyrogenesis of hydrocarbons, 115.
—— on sulphurous oil-fuel, 221.
—— Sulphur in Petroleum Oils, 226, 250, 254.
—— on paraffin wax of Assam, 280.
—— on toluene estimation, 310.
Petrographic correlation, 148, 150.
Petroleum, Science of, 1.
Pitchford, Salop, tar spring, 155, 185.
Pungs (salt licks), 268, 279.
Pyrogenesis of Hydrocarbons, 36.

Redwood, Sir Boverton, on Norfolk oil-shales, 27.
—— on pyrogenesis of hydrocarbons, 113.
—— on geological mapping, 143.
—— on petroleum in England, 184.
—— on fuel-oil combustion, 217.
—— on desulphurising oil, 242.
—— on the Presidential Address, 261.
—— on the Assam Oilfields, 278.
Redwood-Dewar cracking process, 42.
Riddings, Derbyshire, oil-flow, 8, 154, 156, 178.
Rittman cracking process, 66, 115, 119, 321.

Saltwater in fuel oil, 220.
Scotch oilshale, 8.
Secondary rocks, thickness, 182.
Settling-tanks in oil-burning ships, 206, 219, 226.
Shale-oil, sulphur in, 24, 33.
—— desulphurisation of, 25, 27, 29, 33, 233, 242, 245, 304.
Shepton Mallet, Somersetshire, oil-flow, 155, 184.
Shropshire oil-occurrences, 155, 185.
Smith, J., on sulphur in fuel oil, 251.
Somersetshire oil occurrence, 155, 184.
Stackard, S. F., on oil-fuel combustion, 222.
Staffordshire oil-occurrence, 155.
Stratum-contouring, 146.
Submerged oilburner, 224.
Sulphonation of hydrocarbons, 288.
Sulphur as criterion of origin of oil, 228, 248.
—— detention in coal-ash, 33, 219.
—— dioxide (liquid), selective action on aromatic hydrocarbons, 296.
—— in oil-fuel, 219, 221, 234, 251.
—— in Petroleum, 227.
—— in shale-oil, 24, 33, 230, 239, 249.
Surface-contour indicative of geological structure, 140, 150.
Sussex oil-shale, 11.
Sutherland, D. A., on oil-burning in metallurgy, 224.
Swinburne, J., on desulphurisation of oil, 253

Technologists on commercial Boards, 259.
Tectonic structure of S.E. England, 159.
Temperature in pyrogenesis, 75.
Tertiary movements in E. Anglia, 164, 177.
Test-drilling, dry, 35.
Thermo-chemistry of pyrogenesis, 72.
Thiophane and thiophene, 231, 244.
Thole, Dr. F. B. The Pyrogenesis of Hydrocarbons, 36.
—— on desulphurisation of oils, 246.
—— on toluene estimation, 318.
Trienes, 116, 120.

"Vagaries" of Nature, 192.
Viscosity of fuel-oil, 196.
—— reduced by heating, 207.
—— —— by added naphthalene, 208

Wales occurrences of oil, 154, 178, 185.
Wallace, C. W., obituary, no. 9. p. ix.
Water in fuel-oil, 196, 206, 219.
Wells, J., on Norfolk shale-oil, 34.
Wharfe axis, 166.

Yorkshire oil occurrences, 154, 180.